McKinsey Global Institute

# Curbing Global Energy Demand Growth: The Energy Productivity Opportunity

May 2007

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## McKinsey Global Institute

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# Curbing Global Energy Demand Growth: The Energy Productivity Opportunity

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# Preface

This report is the result of a yearlong effort by the McKinsey Global Institute (MGI) and McKinsey's Global Energy and Materials (GEM) Practice to understand the microeconomic underpinnings of global energy demand. It is the second of a two-part series to introduce microeconomic analysis of end-use segments to the global energy debate.

A group of leaders from McKinsey's Global Energy and Materials Practice, Pedro Haas, Scott Nyquist, Matt Rogers, and Jonathan Woetzel, provided strong guidance to our project throughout. The project team was led by Jaana Remes and Jaeson Rosenfeld, Senior Fellows at MGI. The project team included Arpit Agarwal, Florian Bressand, Rahul Gupta, Anders Havneraas, Maya Jolles, Paul Langley, Shawn Liu, Fabrice Morin, Laurent Poncet, Sebastian Roemer, Erin Tavgac, and Peter Yeung.

Our project has benefited from support from many colleagues around the world, and we would particularly like to thank Ivo Bozon, Odd Christopher Hansen, Scott Andre, Warren Campbell, Tim Fitzgibbon, Morten Jorgensen, Mike Juden, Alan Martin, Augusto Moreno, Greg Terzian, and Jin Yu. We would like to thank our senior external advisors Adrian Lajous and Robert Mabro for their valuable input. We also owe thanks to David Fridley, Mark Levine, Jiang Lin, Lynn Price, and Nan Zhou from the Lawrence Berkeley National Laboratory for their contributions.

We would like to thank our colleagues in McKinsey's knowledge services, Tim Beacom, Egor Chistyakov, Barbara Fletcher, Haruko Nishida, Jessica O'Connor-Petts, Karin Ohlenforst, Mohan Reddy, Daniela Rodrigues, Reiko Seigo, Susan Sutherland, Karen Victory, and Peter Zheng, along with Janet Bush and Susan

Lund for providing editorial support. We would also like to thank MGI practice administrator Deadra Henderson and MGI executive assistant Sara Larsen.

This work is part of the fulfillment of MGI's mission to help global leaders understand the forces transforming the global economy, improve company performance, and work for better national and international policies. As with all MGI research, we would like to emphasize that this work is independent and has not been commissioned or sponsored in anyway by any business, government, or other institution.

Diana Farrell
Director, McKinsey Global Institute
May 17, 2007
San Francisco

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# Executive summary

In an era of high oil and gas prices, concerns about $CO_2$, and uncertainty about the security of supply, energy policy has come to dominate political discourse around the world. To date, the energy debate has centered largely on how to secure future energy supply and how to finance research into alternative sources of fuel. While these are important, no energy policy can be complete without a comprehensive understanding of the size of the demand abatement opportunities—and how these can be captured in an economically sound way. After all, what's the point of increasing supplies that are destined to be wasted?

The good news is that there is a very large opportunity to contain energy demand growth in economically attractive ways—and, in the process, cut $CO_2$ emissions. Research by the McKinsey Global Institute (MGI) and McKinsey's Global Energy and Materials Practice finds that a concerted global effort to boost energy productivity—or the level of output we achieve from the energy we consume—would have spectacular results. By capturing the potential available from existing technologies with an internal rate of return (IRR) of 10 percent or more, we could cut global energy demand growth by half or more over the next 15 years.

Our yearlong research project examined energy demand in major regions and sectors, how company and consumer behavior affect demand, and the impact of existing energy policies. We then built a model of global energy demand and productivity evolution to 2020. With current policies, we find that energy demand growth will accelerate significantly across all scenarios. In our base case, energy demand will grow 2.2 percent annually to 2020—significantly faster than the 1.7 percent growth rate observed since 1986. However, our research also shows that enough opportunities are available to boost energy productivity by 135 quadrillion BTUs (QBTUs)—the equivalent of 64 million barrels of oil per day, or almost 150 percent of the entire US energy consumption today. Capturing these opportunities would reduce energy demand growth to less than 1 percent annually—without compromising economic growth.

While market forces alone will not lead to this outcome, targeted policies can overcome the policy distortions and market imperfections that are currently acting as barriers to capturing higher levels of energy productivity.

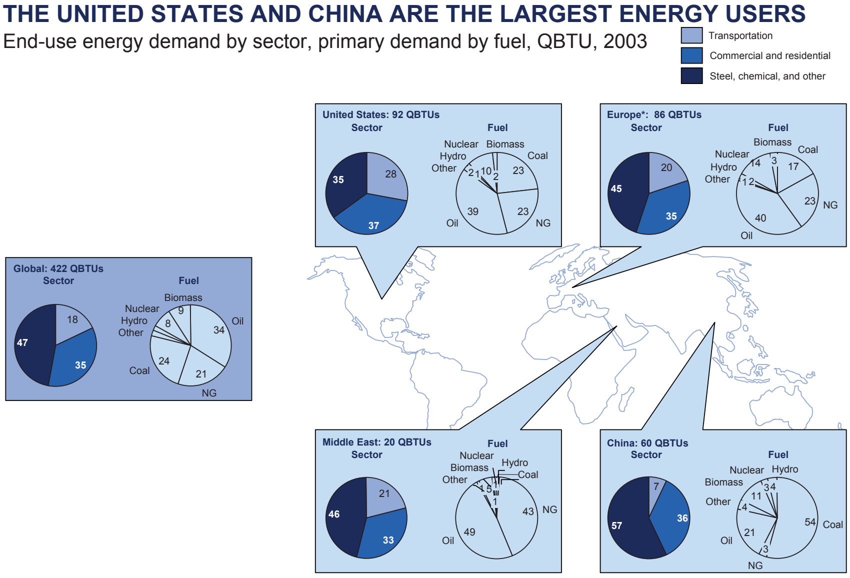
## GLOBAL ENERGY DEMAND GROWTH WILL ACCELERATE

In 2003, global energy consumption reached 422 QBTUs of energy—the equivalent of 200 million barrels of oil per day. The United States and China were the two biggest consumers, with four of the largest end-use sectors worldwide (Exhibit 1). Consumers are increasingly the driving force of energy consumption as the world economy has shifted away from industry and toward less energy-intensive service industries. Sectors that have the characteristics of consumer goods—such as residential and commercial buildings and road transportation—will drive 57 percent of energy demand growth to 2020.

**Exhibit 1**

### THE UNITED STATES AND CHINA ARE THE LARGEST ENERGY USERS

End-use energy demand by sector, primary demand by fuel, QBTU, 2003




* Includes Northwestern Europe, Mediterranean, North Africa, Baltic and Eastern Europe.

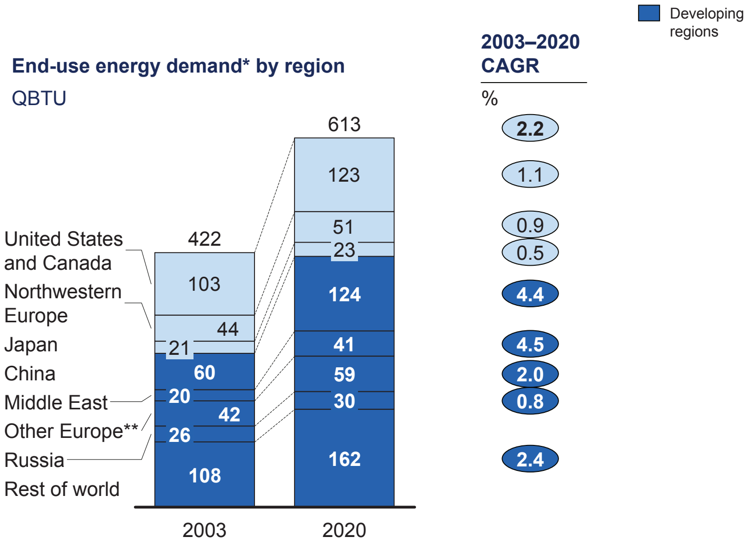
Source: IEA; MGI analysis

The world has also learned how to get more from the energy we consume. Energy productivity grew by 1.3 percent a year between 1980 and 2003. Going forward, we calculate that it will continue to grow by some 1 percent a year to 2020, leaving it 18 percent higher than it is today. Shifts toward less energy-intensive activities will account for just over half of this growth; rising energy efficiency for the rest.

Yet this "business-as-usual" increase in energy productivity is not enough to stop energy demand growth from accelerating. We see demand growth averaging 2.2 percent a year to 2020 in our base-case scenario, with faster growth across all scenarios than that observed since 1986 (Exhibit 2).[1] Rapidly growing developing countries will account for an overwhelming 85 percent of energy demand growth to 2020. China alone represents one-third of the total growth, due to high demand for cars and appliances from its burgeoning middle class and the sustained strength of industrial energy demand. Another fast-growing region is the Middle East, where oil revenues are boosting GDP growth and energy subsidies encourage energy-intensive development.

**Exhibit 2**

**ENERGY DEMAND GROWTH ACCELERATES TO 2.2 PERCENT A YEAR TO 2020**




* Transformation losses (power generation. refining) allocated to end-use segments.
** Includes Baltic/Eastern and Mediterranean Europe and North Africa.
Source: MGI Global Energy Demand Model

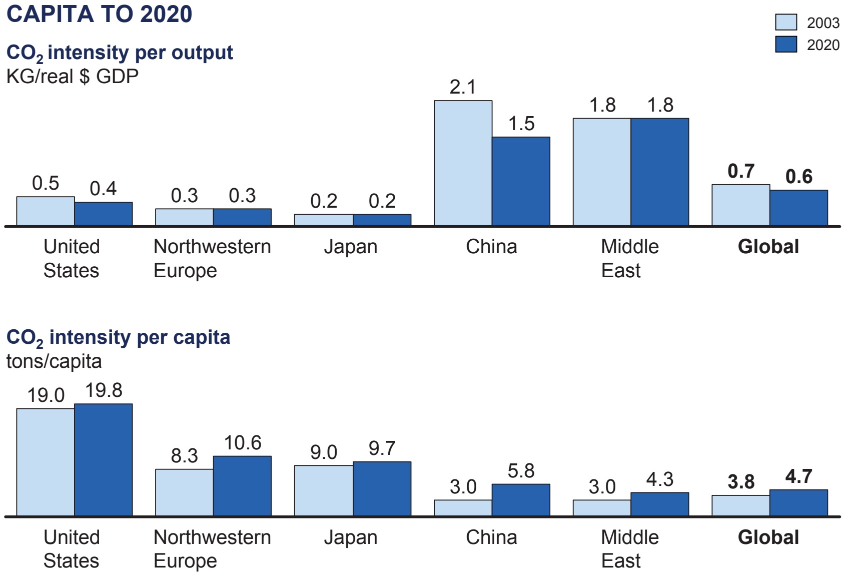
By 2010, China will have overtaken the United States and Europe as the world's leading $CO_2$ emitter. However, the United States will remain the world's largest emitter on a per-capita basis in 2020, and the Middle East the most energy-intensive (Exhibit 3). Global $CO_2$ emissions will grow by 2.4 percent annually

1 Our base case assumes a 3.2 percent annual global GDP growth rate and a $50 per barrel oil price. With alternative GDP growth and oil-price assumptions, our global energy demand growth projections to 2020 range from 1.7 to 2.8 percent annually.

to 2020—more quickly than global energy demand—because of a shift to a more $CO_2$-intensive fuel mix, notably, fast-growing coal-intensive power demand in developing economies.

**Exhibit 3**

**THE UNITED STATES WILL REMAIN THE LARGEST EMITTER OF $CO_2$ PER CAPITA TO 2020**




Source: MGI Global Energy Demand Model

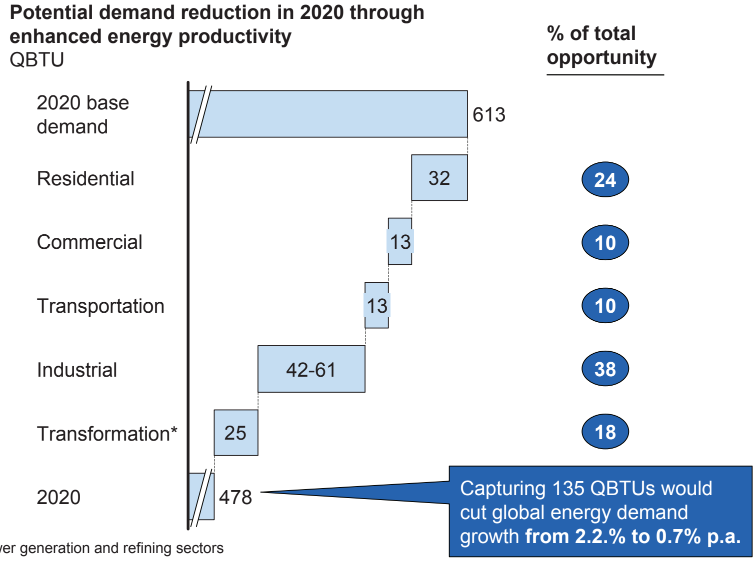
## IMPROVING ENERGY PRODUCTIVITY COULD CUT ENERGY DEMAND GROWTH BY AT LEAST HALF

There is a great opportunity to reduce worldwide energy demand growth to less than 1 percent annually—simply by using energy more productively. We identify a potential to reduce demand of between 125 and 145 QBTUs, the equivalent of 20 to 24 percent of projected end-use demand in 2020 (Exhibit 4). Rather than being expensive, these investments to boost energy productivity use existing technologies with an IRR of 10 percent or more. They thus free up resources to increase consumption or investment elsewhere. Capturing this opportunity would contribute up to a half of the greenhouse gas (GHG) emission abatement required to cap the long-term concentration of GHG in the atmosphere at 450 to 550 parts per million (a range that experts suggest is required to prevent the global mean temperature from increasing more than 2° Centigrade).

The most substantial productivity improvement opportunity is in the global residential sector, which is also the world's largest consumer of energy with 25 percent of global end-use demand. By implementing available technologies such as high-insulation building shells, compact fluorescent lighting, and high-efficiency water heating, the sector's energy demand growth would more than halve, from 2.4 percent a year to only 1.0 percent a year. This alone would reduce the sector's 2020 energy demand by 32 QBTUs—or 5 percent of global end-use energy demand in 2020.

**Exhibit 4**

LARGE OPPORTUNITIES FOR IMPROVING ENERGY PRODUCTIVITY ARE AVAILABLE ACROSS SECTORS…




* Power generation and refining sectors

Source: MGI analysis

Electricity generation and distribution is another area with significant potential. Investing in the most efficient technologies could increase conversion rates to up to 55 percent. Implementing only those investments with an IRR of 10 percent or more would reduce this sector's demand growth from 2.3 percent to 1.7 percent. This would reduce global energy demand in 2020 by 21 QBTUs, the equivalent of 3 percent of the total.

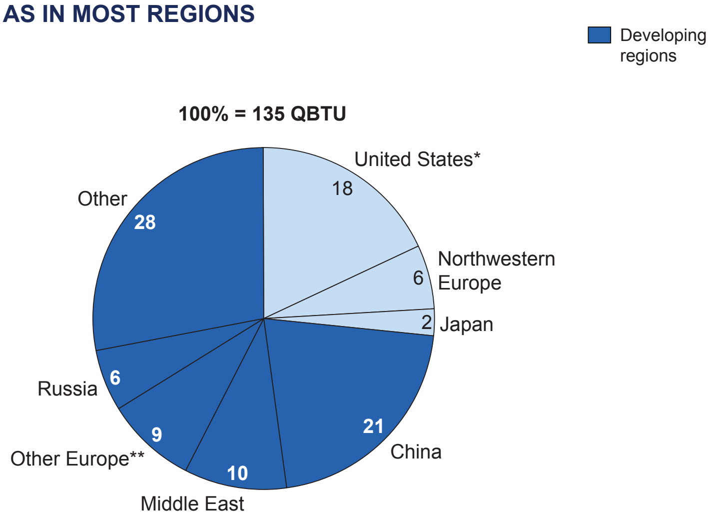
Developing regions can contribute more to improving energy productivity, largely because they tend to start from a much lower base, grow more rapidly than developed economies—and thus can adopt the latest technologies for new capital at a lower cost (Exhibit 5). We estimate China's overall energy productivity opportunity to be 28 QBTUs in 2020, or close to 5 percent of global energy demand. The choices it makes will therefore be crucial.

## TARGETED POLICIES CAN OVERCOME MARKET IMPERFECTIONS

Market forces alone will not capture the substantial potential for higher energy productivity and lower energy demand growth. Our research shows that even a sustained oil price of $70 a barrel would not have a significant impact on energy demand. This is because most energy prices that consumers pay don't reflect global oil prices and because higher oil revenues tend to boost energy-intensive consumption in oil-exporting countries, which counteracts the decline in oil-importing regions in some end-use segments like road transportation.

**Exhibit 5**

**... AS WELL AS IN MOST REGIONS**




* Includes Canada (2.4 QBTU opportunity)
** Includes Baltic / Eastern and Mediterranean Europe and North Africa
Source: MGI analysis

Global energy markets are rife with market inefficiencies and distortions that explain why consumers and companies fail to capture the savings from higher energy productivity. Consumers lack the information and capital they need to become more energy productive, and tend to make comfort, safety, and convenience priorities. The small and fragmented nature of energy costs tends to deter businesses from seeking higher energy productivity. In addition, a range of policies dampen price signals and reduce incentives for end users to adopt energy productivity improvements. These include, for instance, fuel subsidies in many oil-exporting countries; lack of metering in residential gas usage in Russia and elsewhere; and widespread energy subsidies to state-owned enterprises.

Targeted policies to remove distortions and overcome market imperfections can help capture the opportunities that are available to improve energy productivity—and reduce energy demand growth. We highlight the impact of some of the policy options below:

- Ending fuel subsidies would cut demand for transportation fuels by 3 million barrels a day. In the Middle East, for instance, average fuel consumption per vehicle is more than double the average that prevails in countries without fuel subsidies. Iran spends some 16 percent of GDP on energy subsidies. Removing the region's subsidies would cut its demand for road-transportation fuel by almost half.

- Tightening fuel-economy standards would accelerate the introduction of fuel-saving technologies. Europe and Japan already plan a progressive increase in standards. If the United States were to match these efforts, global fuel economy would increase by four miles per gallon by 2020, equivalent to cutting demand for petroleum products by 4 million barrels per day.

- In the residential sector, standby power consumption ranges from 20 to 60 watts, equivalent to 4 percent to 10 percent of total residential energy consumption. Yet the technology is available to reduce standby power to 1 watt and a global standard could mandate this reduction. Governments could mandate compact fluorescent lighting as is the case in Australia. If CFL reached 30 percent penetration, this alone would capture up to 3 percent of the sector's potential for higher energy productivity.

- China has recently introduced specific policies for commercial buildings, including building codes, office equipment standards, and labeling. However, the government could further enforce implementation—through audits targeting largest builders, for example—to increase the impact of the policy, given that estimated compliance for new construction is less than 5 percent.

- Innovative power companies and energy intermediaries such as energy service companies in the United States can help consumers make more-informed energy choices and profit from the positive-return energy savings not fully captured today. To enable this, utilities can implement technologies that allow consumers to see the actual cost of their appliance choice, say, in a more disaggregated utility bill.

- Industrial companies sometimes apply IRR hurdle rates of 20 percent or more to energy-saving investments. Governments can encourage higher energy productivity through demonstration projects and energy audits, as well as consider subsidies or tax credits to companies implementing certain energy-conservation technologies. They might also opt to finance energy-conservation projects at low rates.

• • •

The challenges of climate change and the security of energy supply often appear so huge as to be insurmountable. However, we already have in our hands the potential to abate accelerating energy demand in a practical, economically attractive way.

# Energy productivity: The key to curbing global energy demand growth

## INTRODUCTION

Policy makers around the world are beginning to appreciate that containing energy demand is as important as developing new sources of supply. The European Union (EU) has committed to cutting its projected 2020 energy demand by 20 percent, while China plans to reduce the energy intensity of its economy over the next three years. However, there is widespread fear that achieving these goals will require large costs and economic sacrifices.

This report shows that a concerted global effort to boost energy productivity—the level of output we achieve from our use of energy—could reduce demand growth substantially. Collectively, we have the potential to cut global energy demand by 135 quadrillion British thermal units (QBTUs)—the equivalent of 64 million barrels of oil per day, or almost 150 percent of the entire US energy consumption today. This would reduce energy demand growth by half to 2020.

Moreover, our research shows that raising energy productivity will not entail the enormous costs that many people believe. Our research is based on employing only the technologies that exist today and that have an internal rate of return (IRR) of 10 percent or more. These investments pay for themselves, and make good economic—as well as environmental—sense. They will thus not deny consumers in developing economies their legitimate aspiration to the same levels of comfort and convenience long enjoyed in the developed world.

The challenges of climate change and the security of energy supply often appear so huge as to be insurmountable. However, we already have in our hands the potential to abate accelerating energy demand in a practical, cost-effective way.

**WHAT IS ENERGY PRODUCTIVITY?**

Like labor or capital productivity, energy productivity measures the output and quality of goods and services generated with a given set of inputs. We measure energy productivity as the ratio of value added to energy inputs, which today is $79 billion of GDP per QBTU of energy inputs globally. This is the inverse of energy intensity of GDP, measured as a ratio of energy inputs to GDP. This currently stands at 12,600 BTUs of energy consumed per dollar of output.

The concept of energy productivity provides an overarching framework for understanding the evolving relationship between energy demand and economic growth. Energy productivity improvements can be achieved either by reducing the energy inputs required to produce the same level of energy services, or by increasing the quantity or quality of economic output.

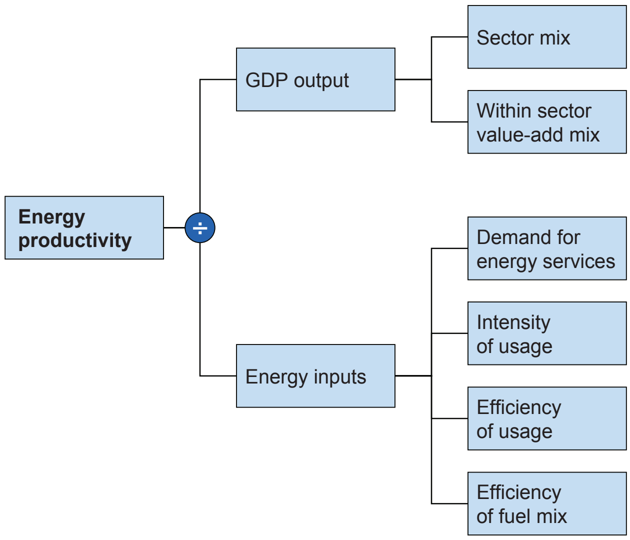
Within each of these, multiple components can change over time (Exhibit 1). The same level of energy services can be produced with fewer inputs if use is less intensive (e.g., smaller appliances), if technical efficiency improves (e.g., higher-mileage car engines), or if fuel mix shifts, say, from biomass to more efficient electricity. In turn, output can grow more quickly than demand for energy services because of sectoral shifts—say, from energy-intensive industrial sectors to services—or from an increasing share of growth taken by non-energy-intensive, high value-added activities within a sector (e.g., increasing share of investment banking versus retail banking). By being explicit about the relative importance of each, energy productivity enables us better to understand the nature and source of change and more effectively seek to improve growth and energy outcomes.

Energy productivity is a useful tool with which to analyze the public-policy aims of demand abatement and energy efficiency because it encapsulates both. By looking merely in terms of shrinking demand, we are in danger of denying opportunities to consumers—particularly those in developing economies who are an increasingly dominant force in global energy demand growth. Rather than seeking explicitly to reduce end-use demand, we should focus on using the benefits of energy in the most productive way.

When identifying opportunities for energy productivity improvements, we focus on changes that rely on currently existing technologies and have an internal rate of return (IRR) of 10 percent or more, and that avoid compromising the comfort or convenience valued by consumers. Our exclusive focus on economic opportunities means that making these investments would benefit the economy by freeing up resources to increase consumption or investment elsewhere.

**Exhibit 1**

ENERGY PRODUCTIVITY DECOMPOSES INTO MULTIPLE COMPONENTS




Source: MGI analysis

## CURRENT GLOBAL ENERGY DEMAND

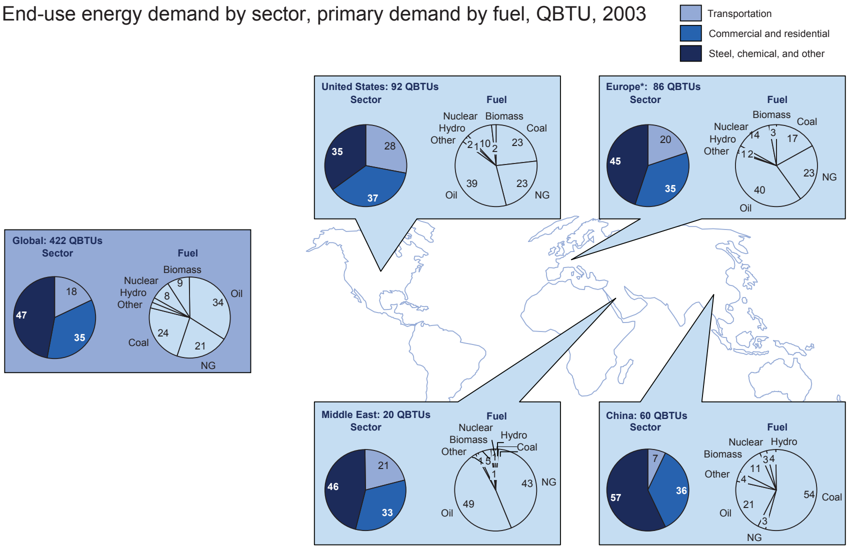
In 1980, the world consumed 284 QBTUs of energy, the equivalent of 134 million barrels of oil a day. By 1990, global energy use had soared to 342 QBTUs of energy—equal to 162 million barrels of oil per day. Since 1986, the world's demand for energy has been growing at a rate of some 1.7 percent a year. By 2003, the latest year for which comprehensive data is available, global energy consumption had hit 422 QBTUs of energy. Oil has continued to be a key source of energy. In 2003, petroleum products accounted for one-third of the total at some 76 million barrels per day, or 142 QBTUs. Coal accounted for 24 percent, or 100 QBTUs, of total usage, and natural gas 21 percent, or 90 QBTUs. The rest of the world's energy consumption was split among myriad fuels, including biomass such as dung and wood, which is still used for cooking and heating in many developing economies.

Not surprisingly, the world's largest energy consumers were the United States and China. The United States consumed 92 QBTUs of energy, 22 percent of the global total. China used 60 QBTUs, or 14 percent (Exhibit 2). These two countries—the giants of the developed and the developing world—are also responsible for four of the largest energy demand sectors globally. US road transport is responsible for 5.4 percent of global energy consumption; US households use 4.5 percent and Chinese households 4.0 percent; and the US commercial sector (including, for example, office and retail buildings, as well as hotels, restaurants, hospitals, and schools) accounts for 3.5 percent of the world's energy use.

**Exhibit 2**

**THE UNITED STATES AND CHINA ARE THE LARGEST ENERGY USERS**

End-use energy demand by sector, primary demand by fuel, QBTU, 2003




* Includes Northwestern Europe, Mediterranean, North Africa, Baltic and Eastern Europe.

Source: IEA; MGI analysis

As economies have shifted toward less energy-intensive service industries, industry's share of global energy demand has been declining. This is particularly the case in developed economies. Consumers are becoming an ever more important part of the energy equation. Sectors that have the characteristics of consumer goods account for 53 percent of global energy demand and 61 percent of demand emanating from the developed world.[1] The residential sector is the largest single user of energy worldwide with 25 percent of total demand. Road transport comes next with 16 percent, followed by the commercial sector with 10 percent and air transport with a relatively modest 2 percent.

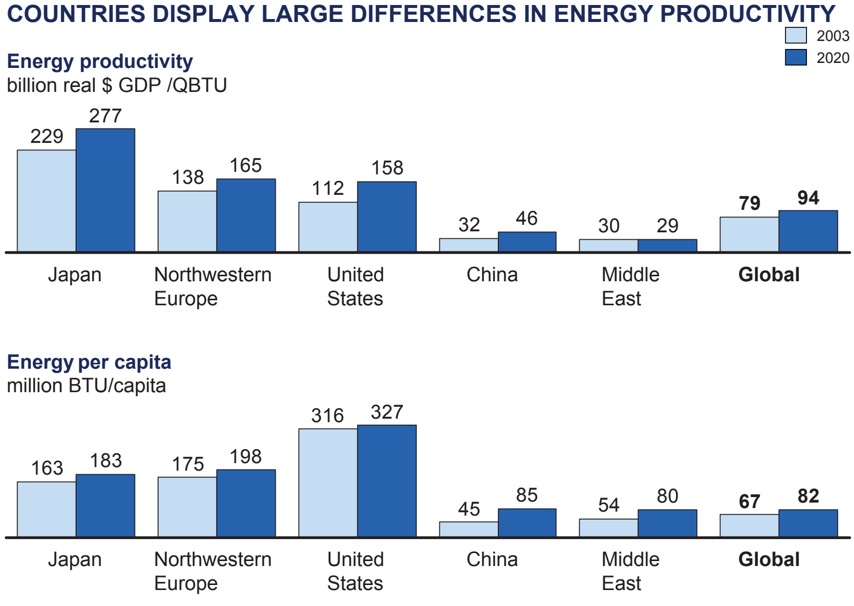
## ENERGY PRODUCTIVITY TODAY

Today's global economy uses 12,600 BTUs of energy per dollar of output produced. This means we produce $79 billion of GDP per QBTU of energy inputs consumed. Yet there are large energy productivity differences between countries and regions. Today, Japan has the highest energy productivity, close to three times the global average, while the Middle East has the lowest, at slightly above

1 These percentages are calculated after allocating power-sector energy consumption and losses to end-use sectors.

one-third of the global average (Exhibit 3). Four factors help explain the levels of observed energy productivity: income level, energy policies, energy endowments, and cost of capital.

**Exhibit 3**




Source: MGI Global Energy Demand Model

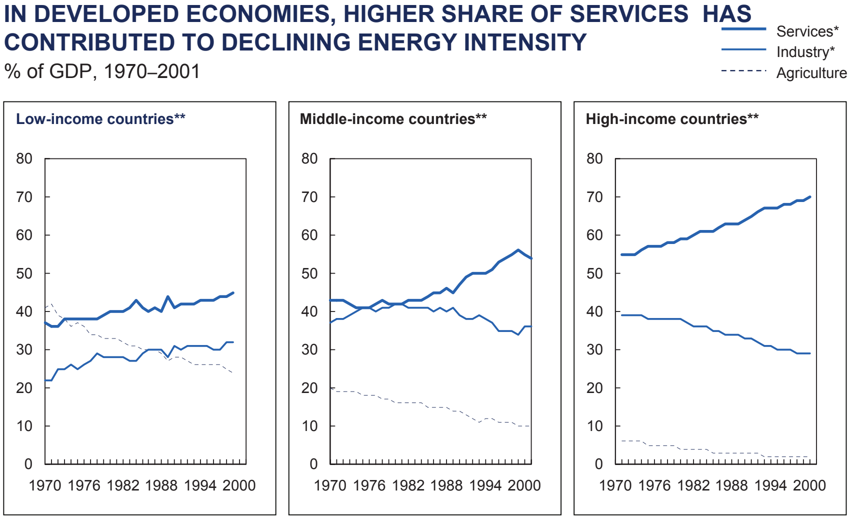
As the incomes of countries rise, the share of more energy-intensive industrial sectors, such as steel, initially increases, but then starts to decline as services become the dominant sector for middle- and high-income economies (Exhibit 4). This shift to less energy-intensive activities increases energy productivity because generating value added requires fewer energy inputs. In addition, the share of higher value-added activities, both within services (the share of investment banking and professional services compared with retailing) and within manufacturing, increases. As a result, energy productivity tends to be lower in middle-income countries or regions where industry accounts for a high share of GDP.

Public policy is another key factor. Widely varied legislative and regulatory regimes across the world go a long way toward explaining sustained differences in energy productivity levels in different countries even with similar income levels. Japan, the global leader in energy productivity with much higher productivity than the United States and Western Europe, already has in place stringent best-practice standards, which are still evolving. These have been an important driver of a deep penetration of more efficient technologies in the country. Conversely, policy in other countries and regions has been an important barrier to higher energy productivity. One example of this is Russia, where a lack of metering in residential gas distribution means that the marginal cost of gas use is effectively zero, leading to very wasteful heating practices. Another instance is fuel subsidies in the oil-exporting countries of the Middle East and Latin America. In the Middle East, for instance, this has led to very high energy intensity in the road-transportation sector, with average consumption per vehicle at double the global average.

**Exhibit 4**

**IN DEVELOPED ECONOMIES, HIGHER SHARE OF SERVICES HAS CONTRIBUTED TO DECLINING ENERGY INTENSITY**

% of GDP, 1970–2001




* Industry includes manufacturing, mining, and construction; services include personal, professional, and public sector services and utilities.

** The World Bank defines middle-income economies as those with per capita GNI in 2003 between $766 and $9,385 USD measured with average exchange rate over past two years.

Source: World Bank; WDI; MGI analysis

The energy endowments of different countries and regions have a direct influence on the industry mix and on public policy. For instance, the Middle East is a major exporter of oil, and it is following an energy-intensive development path and subsidizing fuel for domestic users. China has substantial coal reserves and, at present, coal is its fuel of choice for power generation. A lack of natural energy resources also has an impact on policy. Japan’s strict energy-efficiency standards clearly reflect the fact that the country lacks domestic energy resources and therefore has to import them.

The cost of capital also plays an important role in what level of energy efficiency prevails in a particular country or region because it determines what level of energy efficiency can be adopted for a given amount of new capital or what kinds of energy productivity retrofit investments have a positive return.

## ENERGY PRODUCTIVITY TO 2020

Energy productivity has been growing by an average of 1 percent a year over the past 15 years, and by a cumulative 25 percent since 1980. Over the next 15 years, energy productivity will continue to increase at around the same pace of 1 percent a year. By 2020, this means that global energy productivity will be some 18 percent higher than it is today. In this base-case scenario, the number of BTUs needed to produce a dollar of global GDP will decline to 10,700 in 2020. Our research suggests that the continuing shift in the composition of the global economy toward less energy-intensive activities will contribute just above half of the overall global productivity improvement we project to 2020. Assuming no step-change in energy policies, energy-efficiency improvements will contribute the remainder.

Breaking this down geographically, virtually all regions will see their energy productivity increase. The one exception is the Middle East, which is continuing on an energy-intensive development path that is contributing to declining energy productivity of some 0.3 percent a year. Overall, developing economies will see the fastest increases in energy productivity—at an average rate of 1.8 percent a year (Exhibit 5). Much of this increase will be due to the fact that their GDP will be growing more rapidly than that of developed countries and to the introduction of new, more energy-efficient capital stock, both buildings and equipment. There are, of course, variations within countries among different sectors. In China, for instance, the large installed base of coal-power plants will improve energy efficiency by only 1.2 percent a year to 2020. However, the energy efficiency of residential buildings will improve by 2.0 percent per annum and commercial-sector buildings by 1.5 percent a year due to rapid growth in floor space and policies supporting the Chinese government's current target of reducing energy intensity by 20 percent.

## GLOBAL ENERGY DEMAND GROWTH WILL ACCELERATE

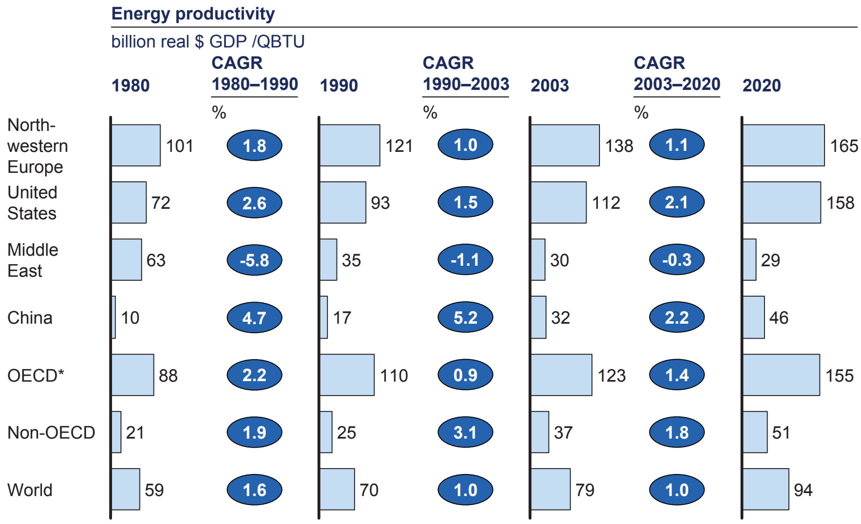
The bottom line, however, is that the increase in energy productivity we project is not enough to stop energy demand growth from accelerating over the next 15 years. This is largely because of rapid GDP and energy demand growth in developing economies.

In our model, the base-case scenario assumes an oil price of $50 per barrel and global real GDP growth of 3.2 percent a year to 2020. Under this scenario, global energy demand will grow by 2.2 percent a year from 422 QBTUs in 2003 to 613 QBTUs in 2020 (Exhibit 6). Energy demand grows even more quickly—at 2.8

percent—if we assume more rapid GDP growth and $30 oil prices. Conversely, a lower rate of GDP growth and a $70 a barrel oil price would reduce energy demand growth to 1.7 percent a year.[2] It is startling, however, that at even the lowest growth scenario, global energy demand will still be growing as fast as the 1.7 percent average annual growth rate observed since 1986.

**Exhibit 5**

**ALL REGIONS EXCEPT THE MIDDLE EAST WILL INCREASE THEIR ENERGY PRODUCTIVITY LEVEL**




* Including North Africa.
Source: IEA; MEI; Global Insight; MGI analysis

### Rapid developing-country energy demand growth

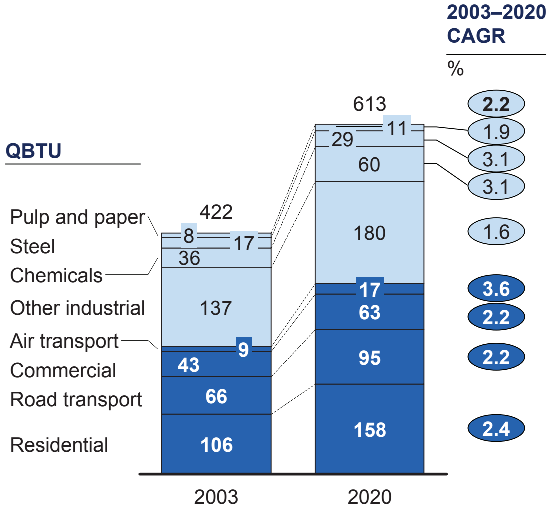
Developing countries will account for an overwhelming 85 percent of energy demand growth to 2020 (Exhibit 7). China, with six out of the top ten sectors in the global-growth league, will be a huge part of the story. With 4.4 percent annual energy demand growth over the next 15 years, China will account for more than one-third—34 percent—of the global total. Chinese car penetration grows more quickly than previously expected as the Chinese middle class expands and car prices continue to decline. Similarly, appliance penetration in households will expand rapidly.[3] The demand for energy from Chinese industry will also rise,

2 Our high and low GDP growth scenarios assume 2.5 and 3.9 annual growth rate for global GDP to 2020, with variations from the base case in different regions. For China and India, we assume plus or minus 2 percent change in GDP growth from base assumptions; for other developing economies, plus or minus 1 percent; and for developed economies, plus or minus 0.5 percent.

3 Diana Farrell, Eric Beinhocker, Ulrich Gersch, Ezra Greenberg, Elizabeth Stephenson, Jonathan Ablett, Mingyu Guan, Janamitra Devan, *From 'Made in China' to 'Sold in China': The Rise of the Chinese Urban Consumer,* McKinsey Global Institute, November 2006, (www.mckinsey.com/mgi/publications/china_consumer/index.asp)

**Exhibit 6**

## GLOBAL ENERGY END-USE DEMAND GROWTH ACCELERATES TO 2.2 PERCENT ANNUALLY TO 2020

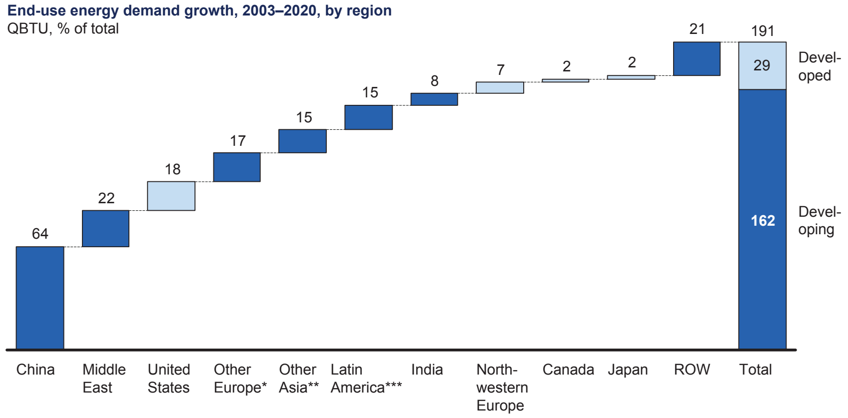



Note: Transformation losses (power generation and refining) allocated to end-use segments.
Source: MGI Global Energy Demand Model

**Exhibit 7**

## DEVELOPING REGIONS, PARTICULARLY CHINA AND THE MIDDLE EAST, WILL DRIVE ENERGY DEMAND GROWTH TO 2020

**End-use energy demand growth, 2003–2020, by region**
QBTU, % of total




* Includes Baltic/Eastern and Mediterranean Europe and North Africa.
** Includes Australia and Korea.
*** Includes South America and Mexico.
Source: MGI Global Energy Demand Model

reflecting the fact that China is at a relatively early stage of industrialization. Chinese steel production is expected to grow by 6.5 percent annually and represent more than 40 percent of global steel output by 2020.

In the Middle East, MGI projects energy demand growth of 4.5 percent a year to 2020, contributing 12 percent of the global total growth. There are two factors behind the rapid growth. First, the $50 oil price in our base case will boost GDP growth and demand for energy from petrochemicals and other industries, as well as consumer demand for residential energy and transportation fuels. Second, our forecast takes into account heavily subsidized fuel prices in the region, which insulates consumers from higher crude prices.

Despite having a comparable GDP growth rate to that of China (6.0 percent annually compared with China's 6.7 percent), India's energy demand will only grow by 1.8 percent in our base case, much more slowly than that of its Asian neighbor. Three factors explain this. First, India's GDP per capita is still only half of China's (just above $3,000 at PPP compared with almost $6,000 in China). The penetration of many energy-intensive consumer products such as cars and household appliances start to take off only when income levels reach $5,000 and above. A much smaller share of Indian than Chinese households will have hit that threshold by 2020.[4] Second, energy-hungry industries such as steel and chemicals account for a higher proportion of the Chinese economy than they do in the Indian economy. Third, as India urbanizes and the electricity network spreads, Indian households are moving away from using very low-efficiency biomass such as dung and wood and toward higher-efficiency fuels—such as gas for cooking. This reduces the overall rate of growth of energy consumption. The same transition is taking place in China, but the residential sector represents only 29 percent of total energy demand compared with 50 percent in India.

### Much slower energy demand growth in developed regions

Energy demand in developed economies will grow more slowly, with 70 percent of the demand growth coming from consumer-driven sectors. US energy demand will grow by 1.1 percent annually in our base case, contributing 10 percent of energy demand growth to 2020. Demand for transportation fuels (both road and air transport) represents 45 percent of the total growth, and industrial energy demand outside chemicals will grow slowly or even decline, as in steel. In Europe, demand will grow more rapidly (1.5 percent annually in our base case) because of more rapid growth in middle-income economies in the Mediterranean and Eastern

4 Diana Farrell, Eric Beinhocker, Sumit Gupta, Jonathan Ablett, Ezra Greenberg, Aadarsh Baijal, Shishir Gupta, Ulrich Gersch, Anupam Bose, *The 'Bird of Gold': The rise of India's Consumer Market*, McKinsey Global Institute, April 2007.

Europe; in contrast, Russia will see slow growth of energy demand (less than 1 percent annually in our base case) as energy productivity continues to catch up from very low initial levels.[5] In Japan, energy demand will stay virtually flat, with growth of only 2 QBTUs overall to 2020. This reflects continuing improvements to Japan's already established and very high level of energy productivity.

**MGI and IEA forecasts compared**

Our base-case forecast is somewhat higher than the most recent World Energy Outlook (2006) from the International Energy Agency (IEA). The IEA sees global primary energy demand growing by 1.8 percent a year in 2004–2020, some 0.4 percent lower than the MGI projection of 2.2 percent.[6] The main reason for this is that the IEA forecasts lower delivered energy demand growth in all the end-use segments, buildings, transportation, and industry.[7] MGI's delivered-demand forecast is 2.3 percent compared with the IEA's 1.8 percent (Exhibit 8). Breaking this down into the individual sectors, the biggest difference is in transportation where MGI projects 2.4 percent energy demand growth compared with the IEA's 1.9 percent. The next largest variation between the two forecasts is in buildings—2.0 percent versus 1.6 percent—and then industrial—2.4 percent compared with 2.1 percent. In contrast, the IEA and MGI have virtually identical projections for power-sector demand.

The divergences between the two sets of projection in some, but not all, sectors reflects different views of the underlying microeconomic dynamics rather than overall macroeconomic assumptions. The IEA's real GDP growth assumption for 2004–2020 is in fact higher than that of MGI (3.7 percent compared with 3.2 percent), while both organizations have similar real oil-price assumptions of $50 real per barrel in 2020.

When we examine the forecasts by region, MGI sees higher growth than the IEA in China (4.0 percent versus 3.3 percent), the Middle East (4.9 percent versus 3.4 percent), and OECD Europe, which includes several large emerging regions including Eastern Europe and Turkey (1.6 percent versus 0.9 percent). The reasons for MGI's higher projections vary from region to region. In emerging Europe, for instance, a takeoff in growth of the vehicle stock to more than 3 percent a year is a key reason for MGI's higher forecast (Exhibit 9).

5 Europe includes Northwestern Europe, Mediterranean and Baltic/Eastern Europe, and North Africa.

6 In its WEO 2006, IEA published forecasts for 2015 and 2030 only. We therefore constructed a 2020 IEA forecast by applying the compounded average 2015–2030 growth rate to the 2015 forecast.

7 Unlike end-use energy demand, delivered energy demand does not include power-sector energy consumption and losses in energy demand generated by each sector.

## Exhibit 8

### MGI'S FORECAST FOR DELIVERED ENERGY DEMAND GROWTH IS HIGHER THAN THAT OF THE IEA

2003–2020

| | MGI $50-oil scenario | | | IEA WEO 2006 | |
|---|---|---|---|---|---|
| **Sector** | **2003** QBTU | **2020** QBTU | **CAGR 2003–20** | **CAGR 2004–20*** | **CAGR 2004–15** |
| Commercial, residential, and agriculture | 108 | 153 | 2.0 | 1.6 | 1.7 |
| Industrial | 104 | 156 | 2.4 | 2.1 | 2.5 |
| Transportation | 81 | 122 | 2.4 | 1.9 | 2.0 |
| Delivered energy across all end-use sectors | 293 | 431 | 2.3 | 1.8 | 2.1 |

* In its WEO 2006, IEA published forecasts for 2015 and 2030 only. The 2020 forecast was constructed by applying the 2015–2030 growth rate to the 2015 forecast.

Source: IEA World Energy Outlook 2006; MGI Global Energy Demand Model

## Exhibit 9

### MGI'S HIGHER DELIVERED ENERGY DEMAND GROWTH COMES FROM ALL THREE MAJOR END-USE SECTORS

2003–2020 delivered energy demand growth

| | MGI $50-oil CAGR | CAGR delta | IEA WEO 2006 CAGR* |
|---|---|---|---|
| **China** | 4.0 | 0,7 | 3.3 |
| Industry | 4.1 | 0,3 | 3.8 |
| Transport | 5.8 | 0,5 | 5.3 |
| Other sectors | 3.3 | 1,2 | 2.1 |
| **Middle East** | 4.9 | 1,5 | 3.4 |
| Industry | 5.3 | 1,6 | 3.7 |
| Transport | 4.7 | 1,9 | 2.8 |
| Other sectors | 4.6 | 1,2 | 3.4 |
| **OECD Europe** | 1.6 | 0,7 | 0.9 |
| Industry | 1.6 | 0,7 | 0.9 |
| Transport | 1.8 | 0,9 | 0.9 |
| Other sectors | 1.4 | 0,4 | 1.0 |

* Reconstructed CAGR 2004–2020 for WEO 2006.

Source: IEA World Energy Outlook 2006; MGI Global Energy Demand Model

### Trends in $CO_2$ emissions

Global energy-related $CO_2$ emissions will grow more quickly than energy demand over the next 15 years—at a 2.4 percent annual rate versus 2.2 percent. By 2020, emissions will reach 35 gigatons, up from 24 gigatons today. The fact that carbon emissions will grow more quickly than energy demand itself seems counterintuitive. However, the reason is that the global fuel mix will shift in an adverse direction. The main culprit will be the fact that coal-intensive power demand will grow more quickly than demand for other final-demand fuels, driven by rapidly rising consumer demand that is particularly power intensive. In addition, there will be a modest shift to more $CO_2$-intensive production within the power generation sector itself.

The world's leading $CO_2$ emitters are currently the United States and Europe. However, by 2010, China will have overtaken them both, and by 2020 will account for 24 percent of global $CO_2$ emissions, compared with 17 percent in 2003. China will contribute a substantial 38 percent of emissions growth to 2020, despite the fact that the $CO_2$ intensity of its GDP is decreasing at nearly the same rate as that of the United States (minus 2.1 percent versus minus 2.0 percent annually). The fact is that China's much more rapid GDP growth will still give a considerable boost to the growth rate of its emissions—4.5 percent compared with 1.1 percent in the United States.

The story is quite different in per-capita terms. China will emit around 6 metric tons per inhabitant by 2020, compared with 20 metric tons in the United States—two-thirds less. If we look at other regions, emissions from the Middle East are also set to grow briskly and will account for nearly 10 percent of global $CO_2$ emissions growth to 2020. The $CO_2$ intensity of GDP in the region will increase slightly (Exhibit 10).

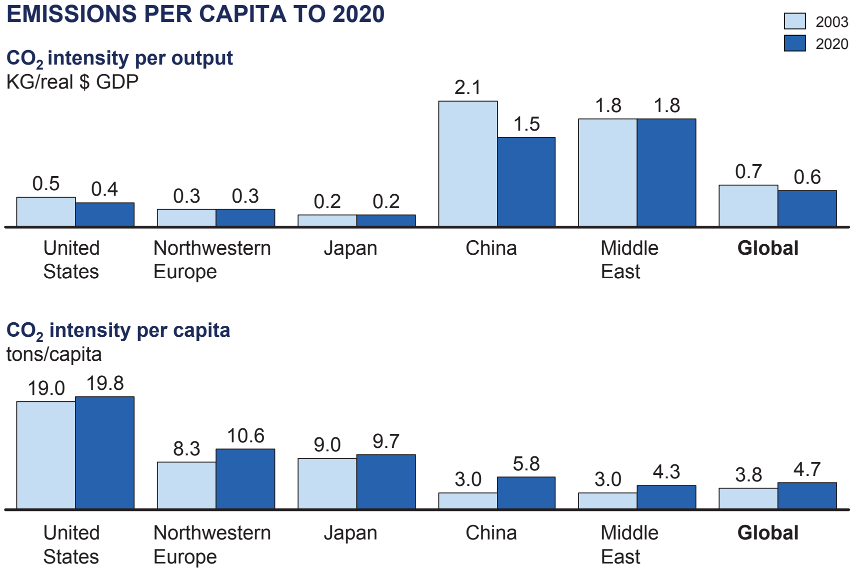
## VARIATIONS IN GDP GROWTH MATTER MORE THAN OIL PRICES

By far the most important determinant of global energy demand is the trajectory of global GDP growth. For all the attention given to the relationship between oil prices and energy demand, the fact is that variations in the price of crude have a minor impact on the overall energy demand.

The rapid acceleration of economic growth in developing countries is one of the major causes for a speeding up of energy demand growth over the next 15 years. However, there is a large degree of uncertainty about how growth will actually turn out in emerging economies.

**Exhibit 10**

**THE UNITED STATES WILL REMAIN THE REGION WITH THE HIGHEST $CO_2$ EMISSIONS PER CAPITA TO 2020**




Source: MGI Global Energy Demand Model

Our research shows a substantial swing in energy demand growth between our low- and high-growth scenarios—from 1.7 percent a year to 2020 to 2.8 percent by 2020.[8] That is the equivalent of a 50 QBTU variation around our base-case demand forecast for 2020 of 613 QBTU demand level. China and the Middle East together account for 46 percent of this swing between the low- and high-growth scenarios.

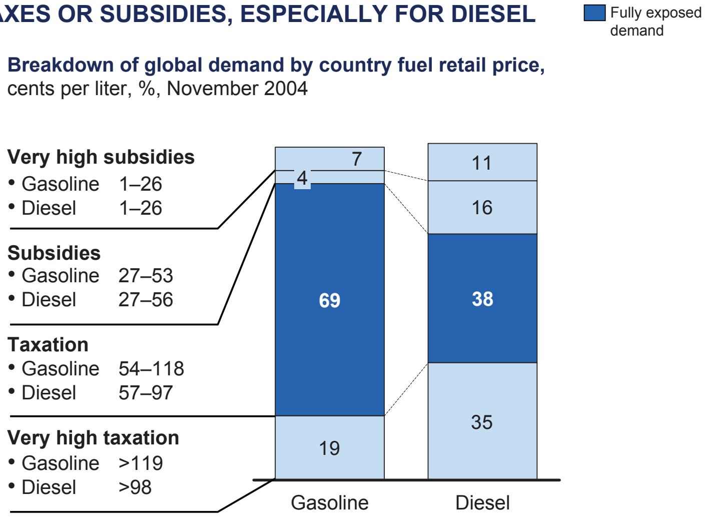
Now take the impact of oil prices on energy demand growth. Here, the swing between low- and high-price scenarios is only 7 QBTUs around our base-case oil-price scenario of $50 a barrel. Oil at $30 a barrel leaves energy demand growth unchanged, while oil at $70 per barrel reduces global energy demand by 7 QBTUs.

There are two reasons why this impact is so small. First, oil-price changes actually have an impact on only a small proportion of the range of energy prices paid by end users. Coal prices don't necessarily correlate with oil price. In the residential and commercial sectors, electricity and gas prices are frequently subject to regulation and therefore changes in the oil price do not necessarily feed through to the prices charged to consumers and businesses. Even in transportation sectors, many consumers are partly insulated from movements in the crude price. One-third of global fuel consumption is either subsidized or heavily taxed (Exhibit 11).

8 For China and India, our high and low GDP growth scenarios assume plus or minus 2 percent; for other developing economies, plus or minus 1 percent; and for developed economies, plus or minus 0.5 percent.

**Exhibit 11**

**A LARGE SHARE OF GLOBAL FUEL DEMAND IS INSULATED FROM OIL PRICE BY TAXES OR SUBSIDIES, ESPECIALLY FOR DIESEL**




Source: GTZ International Fuel prices 2005; MGI analysis

The second reason why even high oil prices have such a limited effect on energy demand is that they have two main effects that go in opposite directions and virtually cancel each other out. In those road-transportation sectors that are not subject to major subsidies or tax breaks and where fuel prices broadly reflect oil prices, the relationship between high oil prices and lower demand is clear. In the United States, for instance, $70 a barrel oil prices result in 15 percent lower fuel demand—the equivalent of 2.5 million barrels a day—than at $30 a barrel in our projections.[9] There is an opposite effect, however, in oil-exporting countries in the Middle East, for example. Not only do higher oil prices accelerate GDP growth and therefore energy demand; in addition, because energy prices are often subsidized and energy productivity is low, there is a very limited demand response even to very high oil prices, further reinforcing rapid energy demand growth.

There is one respect in which higher oil prices do have a significant impact—one that is not often recognized—and that is on the fuel mix. Because both the fuel oil and natural-gas prices paid by power companies tend to increase as oil prices rise, they have a greater incentive to shift to coal. The problem is that this increases greenhouse gas (GHG) emissions.

9 See Road-transport sector case in this report for more on the impact of higher oil prices on road-transport fuel demand.

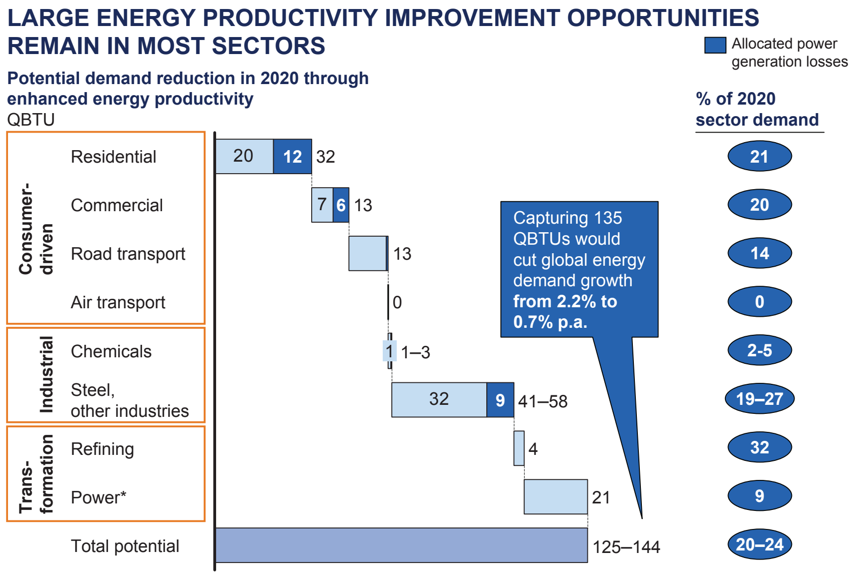
## IMPROVING ENERGY PRODUCTIVITY COULD CUT ENERGY DEMAND GROWTH BY HALF

On current trends, as we have discussed, energy productivity is not increasing strongly enough to prevent energy demand growth from accelerating. However, there is ample scope to do better on productivity and make a spectacular dent in the rate at which demand for energy is increasing.

Our base case sees energy productivity rising by 18 percent by 2020. However, potential exists for an increase of up to 50 percent in the same timescale. Very substantial opportunities to improve energy productivity are found in all end-use segments globally, especially in buildings, power generation, and industrial sectors.

To capture this potential, we are not talking about having to invest in costly research into new technology. Quite to the contrary, MGI research shows that by using *existing* technologies, energy productivity could be raised by between 125 and 145 QBTUs—the equivalent of 20 to 24 percent of projected end-use demand in 2020 (Exhibit 12). Moreover, we base this estimate of the productivity opportunity solely on investments with an IRR of 10 percent or more. We are therefore talking about realistic, cost-effective investments in boosting energy productivity.

**Exhibit 12**




* Additional opportunity after taking into account final power demand savings in end-use sectors.
Source: MGI analysis

If policy makers, consumers, and businesses were to take advantage of all these opportunities to raise energy productivity, this would reduce global energy demand growth to below 1.0 percent a year—less than half the 2.2 percent projected in our base case.

The global residential sector is the largest end user of energy worldwide with 25 percent of global energy demand. It is also the sector with the largest opportunity for improving energy productivity. If it were to implement available technologies such as high-efficiency building shells, compact fluorescent lighting, and high-efficiency water heating, the sector's energy demand growth would more than halve from 2.4 percent a year to only 1.0 percent a year. This alone would reduce 2020 energy demand by 32 QBTUs when the associated power-generation losses are included. This is equivalent 5 percent of global end-use energy demand in 2020.[10]

Reducing current losses from electricity generation and distribution is another substantial opportunity. Power generation used 155 QBTUs—representing a hefty 37 percent of global energy use—to generate 57 QBTUs of delivered electricity in 2003. In short, close to two-thirds of the energy put into the process is lost before it reaches the final end user. Some of this is unavoidable. However, a huge difference can already be observed between older and new technologies. Conversion rates (energy delivered divided by energy used) of only 30 percent are typical of older coal plants. However, they rise to 55 percent or more when advanced combined cycle gas turbine (CCGT) technology is used. Implementing only those investments with an IRR of 10 percent or more would reduce demand growth in this end-use sector from 2.3 percent to 1.7 percent. This would reduce global energy demand in 2020 by 21 QBTU—equivalent of 3 percent of 2020 global end-use energy demand.

The myriad of industrial sectors across the world also offer the promise of large improvements to energy productivity—and therefore the abatement of energy demand growth. The opportunity could range between 40 and 60 QBTUs, or a demand reduction of between 16 and 22 percent. Refining could abate projected 2020 demand by 32 percent, chemicals by 2 to 5 percent, and other industries by 19 to 27 percent.

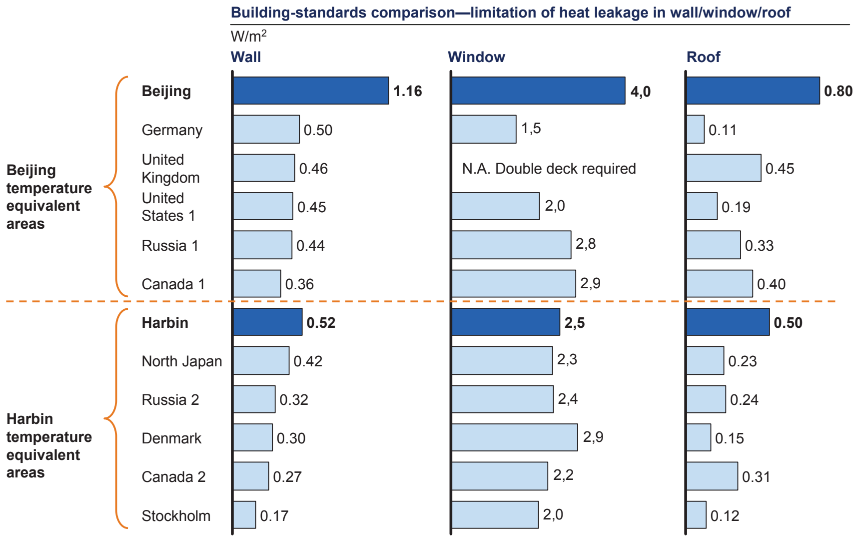
10 These technologies would include installing the tightest building shells in new homes, including chemically treated windows, and the highest-grade insulation. Furthermore, compact fluorescent lighting, reductions in standby power requirements, and driving ever-improving appliance efficiency standards would all be part of the package. Solar water heaters (with appropriate backup when necessary) also show a positive return, at the same time as reducing energy demand.

Developing countries could contribute more to improving energy productivity, largely because they tend to start from a much lower base than developed economies. Their faster growth also creates opportunities to adopt latest, energy-efficient technologies in a cost-effective way. The choices they make will therefore be critical to the future trajectory of energy demand growth.

China, as in so many other respects, will be crucial because of its size and rapidly growing weight in the world economy. We estimate China's overall energy productivity opportunity to be 28 QBTUs in 2020, or 5 percent of energy demand. Take China's power sector alone, which will account for 16 percent of global energy demand growth to 2020. It really matters whether this new demand is met by power plants at current efficiency levels or through the installation of new, high-efficiency coal plants. China's residential sector is another area that could make a large difference. Currently, the energy-efficiency standards in Chinese building codes are significantly below global benchmarks. For instance, China's building-shell standards allow double the leakage of developed-country standards in similar climates (Exhibit 13).

**Exhibit 13**

**CHINA HAS SIGNIFICANT POTENTIAL TO IMPROVE HEATING EFFICIENCY IN BUILDINGS**




Source: ERI; literature search; MGI analysis

## POLICY CHANGES ARE NEEDED TO CAPTURE THE POTENTIAL

Market forces alone will not capture the substantial potential for higher energy productivity and lower energy demand growth. Even sustained $70 a barrel oil prices will not have a significant impact on energy demand.

Global energy markets are rife with market inefficiencies and distortions. Consumers lack the information and capital needed to improve energy productivity and, in the real world, tend to put considerations of convenience, comfort, and safety above cost. And many of them are shielded from the true cost of energy they use because of subsidies and nonmarginal pricing, which further mutes any potential price response.

Some businesses leave investments in higher energy productivity on the table because they don't have strong enough incentives to do otherwise. Part of the reason for this is that many industrial companies around the globe continue to be government-owned. Another is that in many sectors, energy costs are small and fragmented.

If policy makers want to raise energy productivity and be successful in shifting global energy demand from its rapid current trajectory, they have the option of implementing a range of targeted policies to remove these market barriers. We now move onto a more detailed discussion of the reasons why available opportunities to raise energy productivity are not being captured and how to do so.

**MGI'S ENERGY DEMAND MODEL**

Analysts typically forecast energy demand at a global level using top-down correlations to GDP growth. They pair historical year-on-year GDP growth figures with corresponding energy demand growth numbers at both the country and fuel level—for example, oil demand in Japan—and then determine long-term correlations. However, global energy demand is really nothing more than the sum of demand from hundreds of microeconomic sectors—such as China's road-transportation sector and Russia's steel sector. A bottom-up approach is therefore a useful complement to the macro view.

MGI and McKinsey's Global Energy and Materials Practice took a detailed look at each of the main end-use segments in the largest economies globally. We identified the key microeconomic, behavioral, and policy relationships explaining energy demand in each sector. We then aggregated across countries and end-user segments to produce an integrated, dynamic perspective on global energy demand and productivity.

MGI's bottom-up global model builds on detailed microeconomic case-sector studies—a methodology that MGI has nearly 15 years of experience applying to such diverse areas as productivity, offshoring, foreign-direct investment, and capital markets. The energy case studies described in this report cover nine microeconomic sectors, accounting for nearly 60 percent of global energy demand. We use extrapolation techniques for the other 40 percent of global demand (Exhibit 14).

The basis of our analysis is global end-use energy demand. This equals primary demand, but allocates all generation and distribution losses to the corresponding end-use segments. This methodology enables us to focus on a single global demand number and capture the full implications of behavioral and policy factors affecting each end-use segment. We then evaluate the likely fuel mix needed to meet energy demand in these segments.

This is a more appropriate way of thinking about total energy demand and its drivers than the standard division between primary and delivered energy demand.[11] To illustrate the difference, take the sectors where energy demand

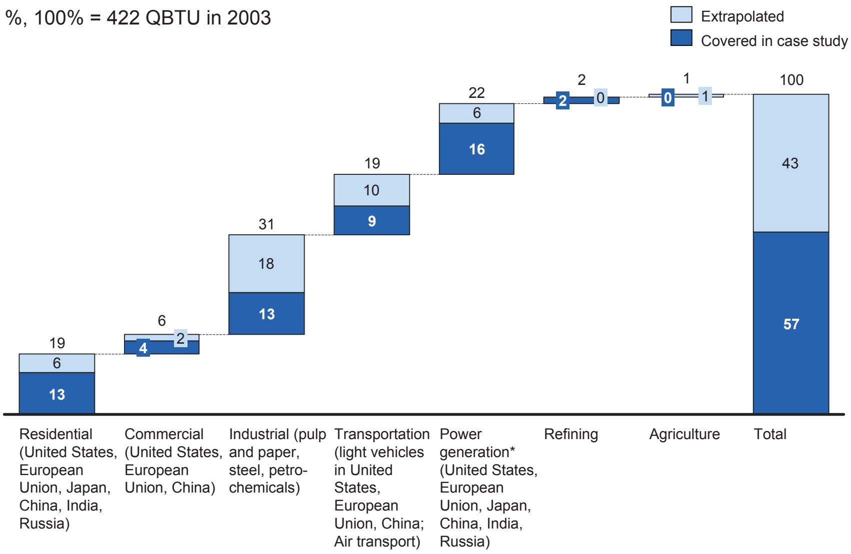
11 These are the two standard definitions used for overall energy demand, only one of which includes energy losses in generation and distribution. Primary energy demand includes both final energy end consumption and the energy lost in generation, transmission, and distribution. This measure is typically used when looking at energy demand by type of fuel, as well as for supply decisions. Delivered energy demand includes only energy end consumption, a measure typically used when assessing energy consumption by sector—or energy intensity in specific sectors. In 2003, the two measures were 422 QBTUs and 319 QBTUs—a difference of more than 30 percent.

tends to behave like a consumer good—residential, road transport, air transport, and commercial. At first glance, these appear to account for only one-third of primary energy demand. However, this ignores the fact that the residential and commercial sectors are the largest users of electricity. When one allocates the production and distribution losses of the power sector across end-use sectors, these consumer sectors represent more than half of total global energy demand, and close to 60 percent of global energy demand growth. The difference between the demand and demand growth figures is due to the fact that the relative size of different sectors changes significantly if we do not account for power-generation losses.

**Exhibit 14**

**MGI SECTOR CASES COVER 57 PERCENT OF GLOBAL ENERGY DEMAND**

%, 100% = 422 QBTU in 2003




* In the rest of this report, power generation demand is allocated to end-use segments.

Source: IEA; MGI analysis

In each sector case, MGI breaks down energy demand into its key components: demand for energy services (how many refrigerators or cars?); intensity of usage (how large and what frequency?); efficiency of usage (what gas mileage or how many kilowatt-hours per cubic meter?); and the fuel mix (how much gasoline versus diesel?). Countries may have significantly different outcomes in the same sector due to varied levels of development, urbanization rates, policy environments, and many other factors more easily observed at the microeconomic level. We then develop dynamic scenarios, which model how these factors might respond to different price and policy environments.

In the residential sector, for example, we see very clear patterns of appliance adoption based on the level of GDP per capita in the country (Exhibit 15). The current and future position of China along the appliance penetration curve will make a real difference to forecasting global energy demand. For instance, while urban areas of China have been traveling along the fast slope of the curve for refrigerator penetration over the past 15 years, they will reach the saturation point of 100 percent in the next 15. So, penetration has driven refrigerator energy demand growth in the past, but future growth will be motivated more by continued urbanization and by size increases in refrigerators.

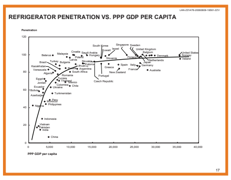
In steel, one of the industrial sectors we examine in detail, two interesting trends are scrap availability and the European Union's (EU) adoption of the Kyoto protocol. Our projections show a shortage of scrap over the next five to ten years, resulting in a higher dependency on energy-intensive production methods. This drives energy demand up over the medium term. In the case of the EU and the Kyoto protocol, the EU could put the highest-cost production in Europe at risk as full-cost mills could be built in Russia or China to displace them.

We have aggregated such sector-level insights into our global energy demand model to produce a single model that forecasts energy demand by country, fuel, and region. This is a unique tool to test different price, policy, global GDP, and other variables, and then state their respective impacts on energy demand.

**Exhibit 15**

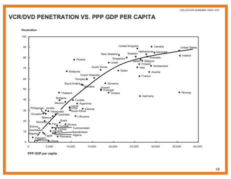
**WE HAVE MODELED FUTURE PENETRATION USING REGRESSIONS OF INTERNATIONAL APPLIANCE PENETRATION VS. PPP GDP/CAPITA**

**Necessities**



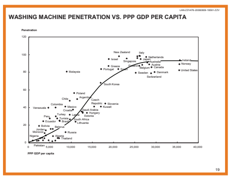

**Steep log-curve**
- Refrigerator
- Color TV

**Normal goods**




**Gradual log-curve or linear**
- Personal computer
- VCR/DVD player
- Vacuum cleaner
- Air conditioner

**Luxury items**




**S-curve/logistic function**
- Microwave oven
- Washing machine
- Dishwasher
- Clothes dryer

Source: Euromonitor; MGI analysis

# Policies to capture the energy productivity opportunity

## INTRODUCTION

The world could cut the growth of global energy demand by half by raising energy productivity—or the amount of output we get from every unit of energy used. Boosting energy productivity would also help to meet broader goals of energy policy, such as mitigating any adverse impact on the environment and helping assuage concerns about how to secure future energy supplies.

Although market forces alone will not lead to this outcome, targeted policies can overcome the price distortions and market imperfections that are currently acting against higher energy productivity. For example, reducing fuel subsidies by 80 percent worldwide would reduce global demand for road-transportation fuel by 5 percent—the equivalent of shaving 2.5 million barrels per day off overall fuel demand.

In this chapter, we discuss the barriers against higher productivity and the opportunities for removing them in each end-use segment. We also examine the implications for policy makers.

## ENERGY PRODUCTIVITY—BARRIERS AND OPPORTUNITIES

A wide range of energy-market failures currently stand in the way of higher energy productivity. They include, for instance, a lack of information available to consumers about the kind of energy productivity choices that are available to them, and agency issues in high-turnover commercial businesses. We estimate that overcoming these market failures—what we might call "nonpolicy" barriers—would achieve 80–90 percent of the total energy savings we believe are available.

Removing the policy-based hurdles that currently hinder efforts to raise energy productivity—most notably those that subject the market to serious distortion, such as energy subsidies—would deliver the other 10–20 percent.

We therefore break down the potential for raising energy productivity into two categories. The first comprises any investments that use currently available technologies and have an internal rate of return (IRR) of 10 percent or more in future energy cost savings, without reducing the end-user benefits from energy consumption.[1] The second opportunity is any reduction in energy demand achieved by removing distorting policies and therefore raising energy productivity to the kind of levels we observe in comparable countries whose energy markets are not subject to distortion.

The end-use segments of global energy demand are very different from one another. Users range from households and individual consumers to large global companies, and the way they use energy and how they make decisions affecting energy productivity vary widely. Naturally, therefore, the barriers they face in raising the level of energy productivity also vary, as do the types of policies most likely to overcome them. The magnitude of the potential for higher energy productivity also ranges widely. To shed light on the nature of these differences, we have analyzed three broad segments—buildings, transportation, and industry.

**Commercial and residential buildings**

Commercial and residential buildings constitute a large segment—35 percent—of global energy demand, and offer substantial opportunities for improving energy productivity. However, it is unlikely that these opportunities can be captured purely on the basis of pricing. The impact of energy prices on demand in this sector—as in others—is currently muted, by both regulated consumer pricing and information imperfections. On top of this, a significant part of the capital in this segment—such as insulation or window materials—has a slow turnaround time, with less attractive retrofit economics. For all these reasons, government standards and incentives for builders and energy intermediaries—particularly power companies—are crucial drivers of energy productivity.

*Residential buildings*

The residential sector represents 25 percent of total global energy demand

1 We use a single IRR as the hurdle rate applicable to all industries in order to be able to compare energy productivity improvement opportunities across sectors. Given the current capital-market returns available for energy users, we consider 10 percent return to be reasonable for the relatively low-risk, operational cash-flow saving investments that comprise the opportunities for improving energy productivity that we identify.

and is the sector with the largest opportunity to raise energy productivity—by the equivalent of 21 percent of the sector's energy demand in 2020. Although residential energy consumption is a large segment in all countries, the drivers of energy productivity shift as incomes rise. In low-income economies, demand for heating and cooking is dominant and changes in the fuel mix are an important determinant of energy productivity. Electrification is a more efficient form of transformation that improves energy productivity. In high-income economies, however, the size of houses and the efficiency of household appliances are more important.

No matter what the income group, consumers tend to make decisions about their energy use based on a broader set of factors than financial considerations alone— such as the convenience and comfort of the fuel and appliances they use. Even if consumers wanted to make cost a bigger priority, they often lack the information they need to make the right choices. For example, most household bills don't break down the electricity consumption of different appliances. And if consumers are not willing to pay for high-efficiency appliances with lower operating costs, then house builders and appliance suppliers are less likely to choose positive-return energy-saving features when they are buying materials or investing in technology. Furthermore, it is difficult for intermediaries to capture these positive-return opportunities because individual residences are such a fragmented market. Taken together, these factors help explain why there are still such large opportunities to boost energy productivity in this sector.

*Commercial buildings*

Commercial energy demand currently represents 10 percent of global end-use demand. The share taken by the commercial sector tends to increase along with income, as higher-income economies tend to have larger service sectors. It is therefore not surprising that developed regions represent 60 percent of current total energy demand in this sector.

Large opportunities for raising energy productivity are found in the commercial sector—20 percent of total sector demand in 2020. It may seem surprising that there are so many untapped opportunities to raise energy productivity in this sector. After all, decisions about energy consumption are being made by organizations, both in the private and in the public sector, that need to manage their costs closely.

Three main reasons explain why so many opportunities to raise energy productivity remain on the table. First, individuals who do not benefit from the savings from lower energy consumption are often those who make the decisions that determine energy productivity. For instance, landlords are not inclined to make investments that benefit their tenants. Conversely, tenants may not want to invest in technology or appliances with higher energy productivity when this would benefit their landlords. Second, commercial buildings have a high turnover rate and this reduces the payback time that many businesses consider acceptable when making energy-saving investments. In other words, they can't count on being able to capture the benefits from these savings because they may have moved on. In the United States, 73 percent of commercial energy users require a payback within less than two years of their investments (Exhibit 1). Third, more than 25 percent of commercial sector energy demand comes from "MUSH" sectors (municipalities, universities, schools, and hospitals) and they operate under stringent capital constraints. Even if an investment offers a high rate of return, they are limited in their capacity to invest. In the United States and some other countries, specialized energy services companies (ESCOs) have emerged to bridge this gap by providing funds for the upfront investment in exchange for a share of the cash flow generated by energy savings (Exhibit 2). However, to date, their impact has been small.

**Transportation**

Transportation demand (both road and air) represents 18 percent of global end-use demand and 52 percent of global petroleum-products demand. Unlike in the building sector, information on both fuel prices and fuel efficiency (or average liters per kilometer or miles per gallon) is readily available to end users. In addition, fuel costs account for a significant portion of the overall expense of transportation. Because of this, fuel efficiency is naturally an important metric for commercial airlines and transportation companies, as well as for individual consumers. As a result, many available opportunities to boost energy productivity have already been identified and implemented.

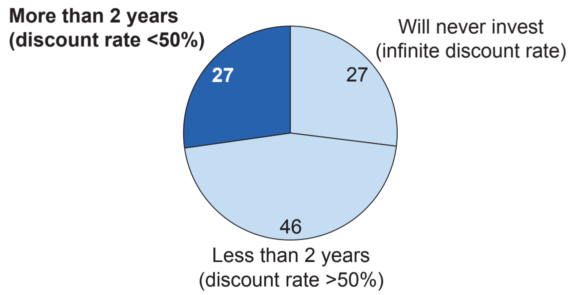
*Road transport*

Road transport currently represents 16 percent of global energy demand and 46 percent of global petroleum-products demand. Without factoring in the impact of policy distortions and overcoming them, which we discuss later on in this chapter, we found opportunities to improve energy productivity in this segment equivalent to 9 percent of global road-transport demand in 2020. Auto manufacturers continue to improve fuel-efficiency technologies in the engines of new models because their customers demand this. For consumers, the fuel economy of the vehicle they drive is an important part of their decision to purchase a particular

## Exhibit 1

### HIGH HURDLE RATES SLOW THE ADOPTION OF MORE EFFICIENT TECHNOLOGIES IN THE COMMERCIAL SECTOR

**Distribution of required payback of US commercial-sector consumers**




**73% of users will disregard energy-efficiency investments with a pay-back time above 2 years (IRR < 50%)**

**Interview with manufacturer of energy-efficient equipment**

> **"In the commercial sector, many energy-efficiency investments have 6- to 12-year paybacks, way above the typical 2-year cutoff used in capital budgeting."**

Source: EIA NEMS Commercial Model Documentation, 2005; disguised client interview, May 2006

## Exhibit 2

### COMMERCIAL-SECTOR CONSUMERS WHO INVEST IN ENERGY EFFICIENCY OFTEN DO SO FOR NONENERGY REASONS

**Definition**

- ESCOs are businesses that offer improvements in end-use energy efficiency by combining engineering expertise with financial services
- Performance contracting, which ties ESCO revenue to achieved savings, is a core part of the business model

**Project size and impact by sector, 2000**

| | Institutional sector (schools, hospitals, etc.) | Private sector |
|---|---|---|
| Share of projects (%) | **73.0** | 27.0 |
| Median project cost ($ million) | 0.9 | 0.3 |
| Lighting-only retrofits (%) | 18.0 | 43.0 |
| Median benefit/ cost ratio | **1.6** | 2.1 |

**Interview with manufacturers of energy-efficient equipment**

> **"A majority of our clients for energy services come from the 'MUSH':**
> - **Municipalities**
> - **Universities**
> - **Schools**
> - **Hospitals**
>
> **"Their main motivation is not to save energy but to overcome the capital shortage they typically face to replace equipment and maintain buildings. For example, savings achieved by projects performed in schools are sometimes used to repaint the walls!"**

Source: Lawrence Berkeley National Laboratory, *Review of US ESCO industry market trends: an empirical analysis of project data*; disguised client interview; MGI analysis model. While this is the norm, it doesn't always apply. Sometimes consumers choose not to pay up front for future fuel savings. This might be because they don't have sufficient access to credit or even because of nonfinancial considerations such as style or comfort. The result is that auto manufacturers aren't making all the positive-return investment in higher fuel economy either—because they cannot be certain that they will recoup the cost from consumers. Interestingly, the relatively fast turnover rate of vehicles makes this segment one in which average energy productivity can change most quickly even in developed economies with large installed bases. Average US fuel efficiency has fluctuated markedly since 1980, for instance.

*Air transport*

Air transport is a small energy end-use segment—with just 2 percent of the global total. However, it is also the fastest growing with an expected compound annual growth rate (CAGR) of 3.6 percent to 2020. In this segment, fuel consumption is a very large share of overall air-transport costs, representing 18 percent of the total airfare. Therefore the fuel efficiency of airplanes is a central decision factor for airlines; and there is both management focus on fuel efficiency and strong incentives for manufacturers to develop fuel-efficient aircraft. As a result, we did not find significant remaining opportunities to boost energy productivity with currently available technologies and with an IRR of 10 percent or more, at least not without compromising consumer comfort (say, by increasing the number of seats on planes).

**Industrial energy use**

Industrial energy use is the largest segment (47 percent of global end-use demand today), but it has a slower-than-average growth rate. Industry is also the most heterogeneous end-use segment. It ranges from highly energy-intensive industries like steel, chemicals, and aluminum to a broad array of less energy-intensive industries such as food processing, textiles, and electronics.

Large opportunities to raise energy productivity remain available across most industrial sectors, collectively accounting for more than one-third of the overall opportunity. A key factor explaining the size of this potential is that many industrial companies around the globe continue to be government-owned (e.g., much of Chinese industrial capacity), or enjoy high levels of regulatory protection, which shields them from competition (e.g., steel, until recently, in the United States and many other countries). Improving performance is hard work for managers, and, without market pressure to do so, many companies will simply not seek to enhance their financial performance by taking advantage of all the opportunities to boost energy productivity available to them. MGI's sector-level work has extensively documented the way this type of disincentive works in the case of labor productivity.[2]

However, even among private industrial companies operating in competitive markets, we find significant (albeit smaller) opportunities for improving energy productivity. There are two main reasons for this. First, in many non-energy-intensive industries, overall energy costs are a small share of overall costs, and opportunities to improve energy productivity are therefore highly fragmented. For this reason, decisions that affect energy productivity are often made by people who are not responsible for ongoing operating costs (e.g., technology choices for new capital or computer-hardware decisions by IT departments). Without a management focus on eking out incremental opportunities for savings (e.g., Toyota's *Kaizen*), many of this fragmented potential is simply not identified. Second, some industrial companies routinely apply very high hurdle rates to all capital investments in their plants. In many basic-materials industries, this may be justified when energy and output prices are volatile and there is uncertainty on whether specific plants will remain open. However, pro-cyclical financing is common. Managers tend to focus on high-return capacity expansion investment when prices are high and hold back investments on low-efficiency, marginal plants for fear of closure when prices are low. Together, these factors limit investment in opportunities to raise energy productivity, despite the fact that they can generate operational cash-flow savings with lower inherent risk.

**Developed and developing economies**

Emerging markets and industrial economies also have somewhat different energy productivity dynamics. High-income economies typically have a large installed capital base in a range of end-use segments (e.g., industrial-production capacity or fleet of vehicles). In contrast, many developing economies start from a lower base of existing capital stock—but will generate most of the energy demand growth in all of the end-use segments that we have analyzed. It is much more economic to incorporate higher energy efficiency features when installing new capital than to retrofit at a later stage. For instance, the additional cost of double, versus single, windows for a new building is a lot lower than replacing already existing single windows with new double ones. For this reason, there are more opportunities to boost energy productivity in installing higher-efficiency capital

2 Multiple sector-level examples of the sources of the large, sustained costs for productivity from public ownership and high levels of protection have emerged from MGI's productivity work (www.mckinsey.com/mgi).

in developing economies between now and 2020 than retrofitting some of the established assets in developed economies.

## HOW TO CAPTURE THE OPPORTUNITY

Capturing the available potential for boosting energy productivity needs action on both the fronts that we have identified: removing distorting policies and overcoming the information failures and other barriers to raising energy productivity that exist in different sectors. These policies have to be calibrated and implemented in ways that will command popular political support. For instance, removing subsidized pricing of energy can be politically difficult because these subsidies are often intended explicitly to alleviate hardship in low-income segments of the population. Policy makers will therefore need to think how to mitigate the difficulties of any transition to a more market-based price approach. More broadly, specific policy solutions vary depending on the end-use segment and initial conditions in each country. We will examine these in more detail in forthcoming regional perspectives on the United States, China, and Europe.

Globally, capturing the opportunities to boost energy productivity that we have identified would reduce expected energy demand in 2020 by up to 24 percent—a total reduction of 125–145 QBTUs (Exhibit 3). This is equivalent to almost 150 percent of the entire US energy consumption today. Opportunities in developed economies represent slightly less than 30 percent of the total, with the remainder coming from developing countries (Exhibit 4).

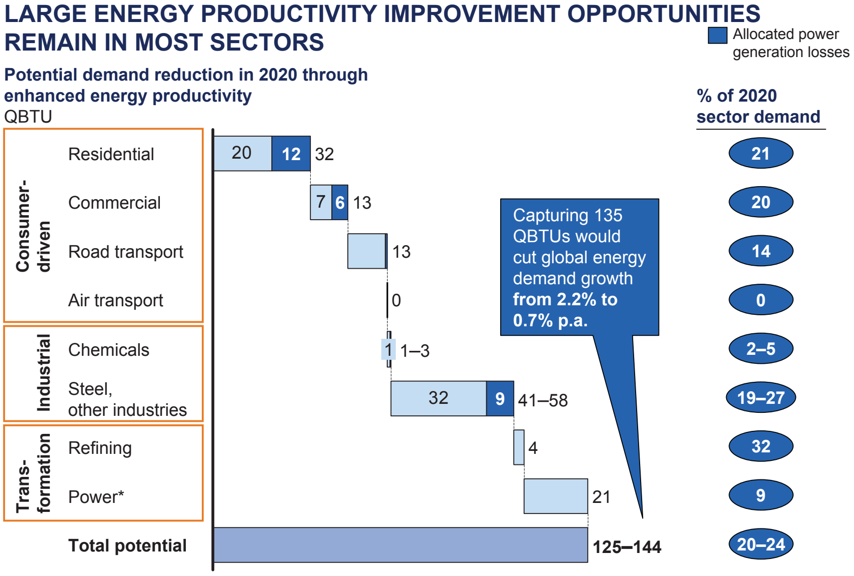
### Overcoming market failures

Overcoming the nonpolicy barriers to raising energy productivity is required to achieve 80–90 percent of the total energy savings we believe are available. Government actions are unlikely to be able to overcome all market failures and, in those cases where their actions are likely to be effective, they face the challenge of designing policies that do not create unnecessary regulatory burdens or unintended consequences elsewhere. Having said that, we believe that large opportunities exist for the broader diffusion of best practices—indeed many of the policies we discuss next have been implemented successfully in some regions. Alongside government action, there are also opportunities for innovative market solutions by private companies.

In the building segment, three policy responses have been proven to increase the capture of higher energy productivity: incentive programs implemented through energy intermediaries (e.g., Energy Efficiency Performance Programs [EEPS] for utilities in the United States); information policies that enable energy users and

## Exhibit 3

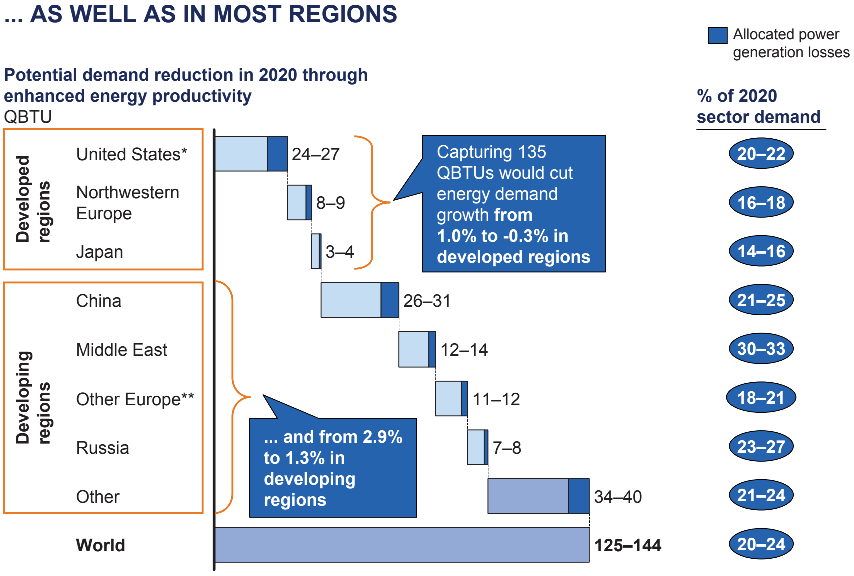
### LARGE ENERGY PRODUCTIVITY IMPROVEMENT OPPORTUNITIES REMAIN IN MOST SECTORS




* Additional opportunity after taking into account final power demand savings in end-use sectors.
Source: MGI analysis

## Exhibit 4

### ... AS WELL AS IN MOST REGIONS

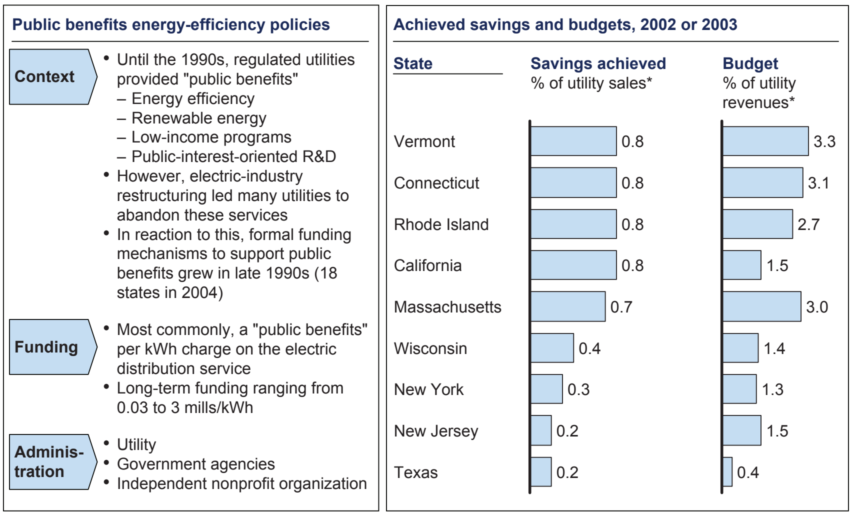



* Includes Canada (2.3–2.6 QBTU opportunity).
** Includes Baltic/Eastern and Mediterranean Europe and North Africa.
Source: MGI analysis

potential intermediaries to gain deeper knowledge about the trade-offs they make, which also helps to overcome principle-agent barriers (e.g., appliance Energy Efficiency Certification in the EU; appliance labeling programs in the United States); and both voluntary and mandatory industry standards (e.g., "Top runner standards" in Japan). In addition, innovative companies (e.g., ESCOs) have started to seek ways to facilitate the capture of positive-return opportunities. For the United States, for example, implementing EEPS nationally would have five times as large an impact on the growth of energy productivity as increasing energy prices to consumers (Exhibit 5).

**Exhibit 5**

**EEPS WOULD BUILD ON OR REPLACE "PUBLIC BENEFITS" ENERGY-EFFICIENCY POLICIES OF THE LATE 1990s**




* Based on revenues and sales of utilities affected by public benefits funding requirements.

Source: *Five Years In: An Examination of the First Half Decade of Public Benefits Energy Efficiency Policies*, ACEEE, 2004

In transportation, the main opportunity relies in those fuel-efficiency-saving technologies in cars that have not been adopted by OEMs because they cannot recover the investment costs from consumers through higher car prices. The policy options for addressing this hurdle include providing more transparent information (e.g., reporting annual savings for average users instead of miles per gallon alone) and setting incrementally more stringent fuel-efficiency standards.

In industrial end-use sectors, providing information on opportunities to boost energy productivity such as demonstration projects and energy audits (Exhibit 6) and ensuring that companies have the right financial incentives to capture this potential, however fragmented (e.g., through privatization), are among the policy tools that are available. Additional options include facilitating the financing of positive-return capital turnover such as upgrading aged steel capacity, and technology policies that ensure the adoption of energy productivity-enhancing technologies in the rapidly growing industrial sectors of developing countries. In the case of chemicals and other energy-intensive sectors that use energy as feedstock, there are only limited opportunities for reducing energy demand. In this context, taxing energy is more likely to lead to the relocation, rather than reduction, of global energy demand.

**Exhibit 6**

**THE REFINERY MARTINEZ DEMONSTRATION UNCOVERED AN ENERGY SAVINGS POTENTIAL OF 12 PERCENT WITH PAYBACK PERIOD OF 1 YEAR OR LESS**

**Primary opportunities identified**

- **Improve the efficiency of fired equipment** – Lowering furnace draft and excess oxygen results in savings from additional heat stack recovery
- **Utility system optimization** – Utility systems can be achieved by minimizing condensation on turbine drives and biasing heat production to the most efficient boilers
- **Maintenance** – Increased investment in insulation repair and heat exchange cleaning
- **Quench elimination** – Focus on optimizing stripping steam and water injections needed for process control
- **Hot rundown between units** – Retain heat in the intermediate processing stream going from one unit to another instead of cooling the streams for storage and releasing them when needed
- **Eliminate waste** – Identify processing that can be eliminated without affecting output
- **Other process changes** – Add hardware and controls to improve process results while reducing energy consumption

- **Energy savings = 6.2 million MBTU, 12% of total energy used**
- **Payback time on capital investment = 0.6 years**
- **More opportunities could exist with longer payback period – 2-year payback period used as maximum hurdle**

Source: US Department of Energy

## Removing distorting policies

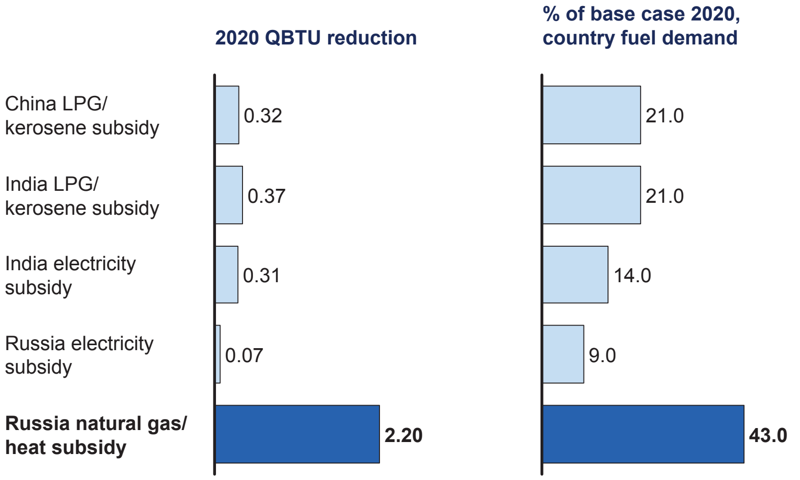
Removing distorting policies represents the remaining 10–20 percent of the opportunities to boost energy productivity that we believe are available.

For buildings, removing subsidized pricing and implementing metered usage where it is not currently in place offer large opportunities. On its own, the removal of the current subsidy on Russian gas promises an opportunity of 2 QBTUs in energy savings by 2020 (Exhibit 7). In addition, there are opportunities for reconsidering pricing regulations that limit the capacity of utilities to set prices to reflect marginal cost—in California, for instance.

In transportation, reducing fuel subsidies by 80 percent globally (largely in the Middle East, Venezuela, and Mexico) would reduce global demand for road-transportation fuel demand by 5 percent—the equivalent of shaving 2.5 million barrels per day off overall fuel demand (Exhibit 8).

## Exhibit 7

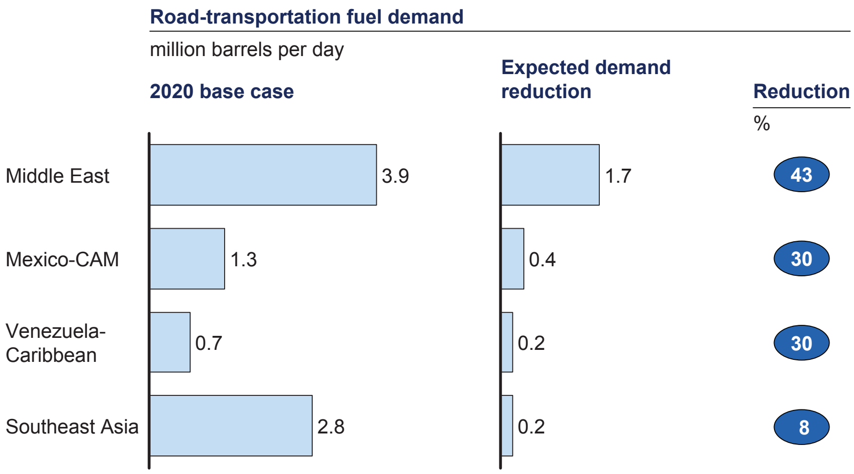
### REMOVING SUBSIDIES – ESPECIALLY RUSSIA'S SUBSIDY ON HEAT – WOULD REDUCE ENERGY DEMAND SIGNIFICANTLY




Source: MGI analysis

## Exhibit 8

### REMOVING 80 PERCENT OF FUEL SUBSIDIES WOULD REDUCE ROAD-TRANSPORTATION FUEL DEMAND BY 2.5 MBD




Source: MGI analysis

In industrial segments, the major opportunities lie in removing energy subsidies and policies that give preferential treatment to particular industries (e.g., power subsidies through arrears for favored industrial operations in Russia), and moving to nongovernment corporate governance to incentivize the capture of higher energy productivity opportunities with a positive return (e.g., improving refining conversion economics in Mexico). Together these represent an opportunity of at least 5 QBTUs.

## BEYOND ENERGY PRODUCTIVITY

Policy makers have other policy goals beyond improving energy productivity. Many governments have expressed an aspiration to reduce energy demand even at a cost—in order to reduce greenhouse gas (GHG) emissions in the case of the European Union, and to enhance energy security in the United States. To provide some microeconomic facts to aid policy makers in their respective debates, we include some policy comparisons for the environment and for energy security. We also discuss the risks associated with using energy as part of industrial policies.

### Environmental concerns

Markets alone do not account for environmental externalities, particularly global ones like greenhouse gases. In fact, the price mechanism can have a perverse effect. Our model shows that a shift from $30 to $70 per barrel of oil causes power generators to shift from oil and natural gas to more $CO_2$-intensive coal, increasing $CO_2$ emissions from the power generation sector by 8 percent globally.

To reduce the environmental costs of energy use but at the same time keep costs low, positive-return opportunities to raise energy productivity are an obvious place to start. Capturing this opportunity would contribute up to a half of the GHG emission abatement required by 2020 to cap the long-term concentration of GHG in the atmosphere at 450 to 550 parts per million (a range that experts suggest is required to prevent the global mean temperature from increasing more than 2° Centigrade)—without a negative impact on the global economy. Beyond this, McKinsey estimates that the rest of the $CO_2$ emission reduction required to meet the target is feasible at a cost of roughly $30–$50 per ton carbon, using well-known technologies.[3]

3 Per-Anders Enkvist, Tomas Nauclér, and Jerker Rosander: “A Cost Curve for Greenhouse Gas Reduction,” *The McKinsey Quarterly*, March 2007 (www.mckinseyquarterly.com/article_page.aspx?ar=1911&L2=3&L3=41).

### Security of energy supply

Some governments aim to reduce domestic oil demand primarily to reduce exposure to risks from oil-import discontinuities. Given the dominant role of transportation in petroleum-product demand, the highest-impact policy options are in this sector. To assess the relative importance of alternative policies for reducing fuel demand (beyond the removal of subsidies that we have described), our work indicates that increasing fuel taxes globally by $1 per gallon would reduce global demand by 5 million barrels per day by 2020; aligning US fuel-efficiency standards to EU and Japanese levels would reduce demand by up to 4 million barrels per day; and doubling projected hybrid market share to 15 percent by 2020 through a combination of subsidies and directives would reduce demand by up to 2 million barrels per day.

### Energy in industrial policy

Some policy makers consider energy policies as a tool for broader economic objectives like economic growth or job creation (e.g., energy subsidies to attract foreign investors in some energy-exporting regions; or investment subsidies for locally produced renewable energy). Although there may be cases where the benefits justify the policies, our sector evidence and MGI's work on the impact of industrial policies on labor productivity suggest that governments should be very cautious for two reasons. First, the economic benefits from subsidized production seldom justify the investment, raising the question on whether the income transfer to subsidized companies is the best use of public funds.[4] Second, favored treatment that shields specific companies from competition tends to lead to economic inefficiencies. To avoid this risk, governments that want to fund the growth of alternative energy, for instance, should take a global perspective and allocate funds competitively to those investors with the highest potential for success and overall impact.

• • •

In the remainder of this report, we will describe the energy profile of the three largest end-use segments—buildings (residential and commercial), transportation (road and air), and industry. Chapter 7 on industrial energy demand includes in-depth case studies covering selected petrochemical segments (ethylene and its derived products, nitrogenous fertilizers, and chlorine–caustic); the steel industry; and the pulp and paper industry. We will describe in more detail the

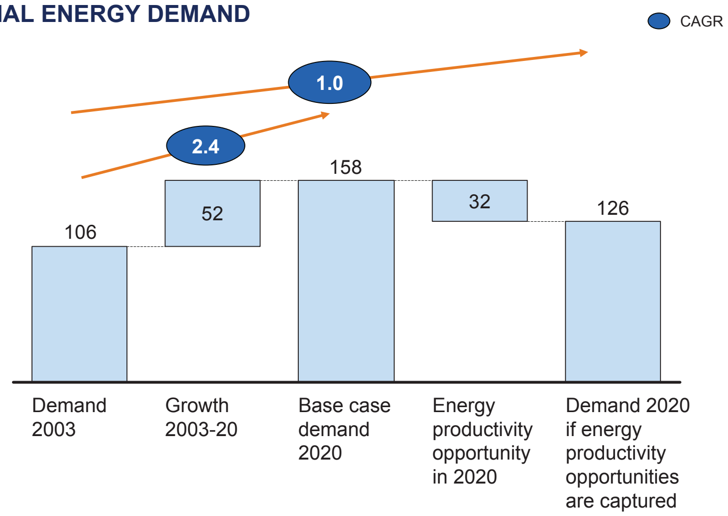
4 *New Horizons: Multinational Company Investment in Developing Economies*, McKinsey Global Institute, October 2003 (http://www.mckinsey.com/mgi/publications/newhorizons/index.asp).

key drivers of energy demand to 2020, as well as the opportunities and barriers to higher energy productivity. We hope that this detailed microeconomic analysis at sector level will help policy makers, businesses, and consumers prioritize the best opportunities to meet their respective aims.

## Residential sector offers the largest energy productivity opportunity

- The residential sector is the single largest energy consumer worldwide, and also the one where the largest uncaptured energy productivity improvement opportunities lie.
- Already planned policies will help moderate the sector's energy demand growth by an amount equal to 15 percent of consumption in 2020. But additional measures, strictly enforced, could boost energy productivity and cut 2020 demand by a further 21 percent.
- In our country case studies, removing subsidies would result in a 3 QBTU reduction in global energy demand—with 2 of the 3 QBTUs coming from removing the district heat subsidy in Russia.
- Energy intensity will grow. For example, in China the average refrigerator will grow from 190 liters to 220 liters.
- The residential sector will experience one of the biggest fuel-mix shifts of any sector to 2020—with the share of traditional renewables like wood and manure decreasing from 37 percent in 2003 to 29 percent by 2020, and power increasing its share from 19 percent to 27 percent.

**RESIDENTIAL ENERGY DEMAND**
QBTU




| | | | | | |
|---|---|---|---|---|---|
| **Global total** % | 25 | 28 | 26 | 24 | 26 |

Source: MGI Global Energy Demand Model

# Residential sector

## I. EXECUTIVE SUMMARY

The residential sector is not only the largest single energy end-use sector, accounting for one-quarter of global demand; it is also where the largest energy productivity opportunities are waiting to be seized.

Residential energy demand will grow at 2.4 percent per annum to 2020, reaching 158 QBTUs, with Europe and North Africa, the United States, and China dominating the picture. As in other sectors, China stands out with a projected growth rate in residential demand to 2020 of 4.1 percent a year, dwarfing the average 0.8 percent growth rate in developed economies. Fuel-mix shifts will be more dramatic in the residential sector than other end-use segments with a large shift away from traditional renewables like wood and manure (37 percent to 29 percent) to power (19 percent to 27 percent) occurring by 2020.

Appliance penetration will be particularly important in driving residential energy demand growth as countries like India and China, which are urbanizing at a rapid rate, see many more households buying goods such as refrigerators and air conditioners.

High energy prices will have very little impact on residential energy consumption—whether the oil price is at $50 or $70 a barrel. This is due to a range of market imperfections, including subsidized pricing, principal/agent problems between renters and owners, and the difficulties inherent in measuring energy savings. These mean that residential energy consumers demand a very high rate of return on energy-efficiency investments.

Policies already planned—including raising energy efficiency standards and the removal of energy price subsidies—will help moderate the sector's energy demand growth by an estimated 24 QBTUs, or 15 percent of total residential energy consumption projected to 2020. However, the sector's energy productivity could be boosted and 2020 demand cut by a further 21 percent—with additional policy measures effectively enforced.

Key areas for policy makers to examine include building shells, more efficient appliances and water heating, compact fluorescent lighting (CFL), and small-appliance standby-power requirements. The removal of price subsidies would, we estimate, capture 10 to 20 percent of the available energy productivity opportunity.

## II. RESIDENTIAL SECTOR ENERGY DEMAND SIZE, GROWTH, AND FUEL MIX

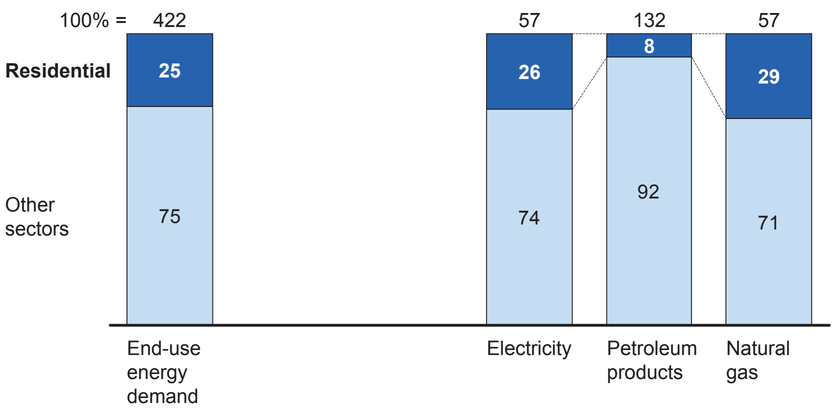
### Size and regional breakdown of energy demand, 2003

The residential sector represents approximately 25 percent of global end-use energy demand in 2003 and will slightly gain share to 2020, reaching 26 percent of end-use energy demand (Exhibit 1). The overall growth rate of the residential sector will be 2.4 percent per annum to 2020, growing to 158 QBTUs. The six case studies we present cover more than 60 percent of global residential energy demand (Exhibit 2).

**Exhibit 1**

**RESIDENTIAL SECTOR REPRESENTED 25 PERCENT OF END-USE ENERGY DEMAND IN 2003**

**Share of residential energy demand in total energy demand, 2003***
QBTU, %



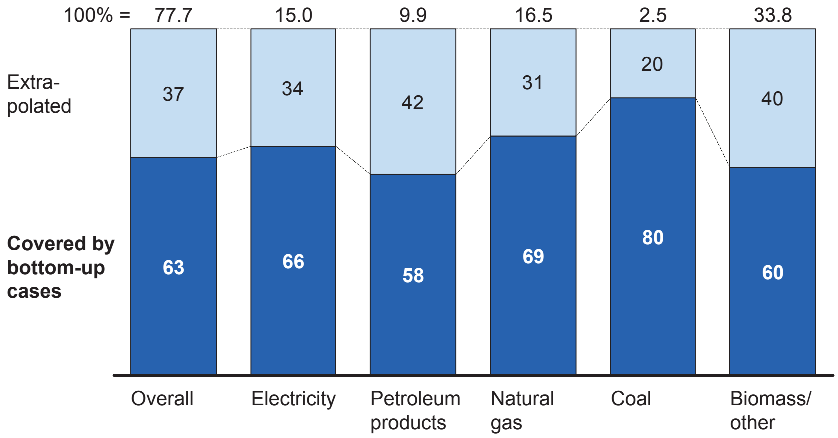

* Total demand includes allocation of losses from refining and power sector; does not consider extra primary demand because of higher share of peak demand in residential sector; individual fuel demand figures are final demand, not end use.

Source: IEA; MGI analysis

## Exhibit 2

### MGI CASE STUDIES COVER 63 PERCENT OF RESIDENTIAL ENERGY DEMAND

**Total final demand for residential fuel, 2003**
QBTU, %




Source: IEA; MGI analysis

Our case studies cover the United States, Europe, Japan, China, India, and Russia. Breaking 2003 residential energy demand into regions, the top four are Europe and North Africa (20.4 QBTUs), the United States (18.9 QBTUs), China (17.0 QBTUs), and India (10.9 QBTUs).

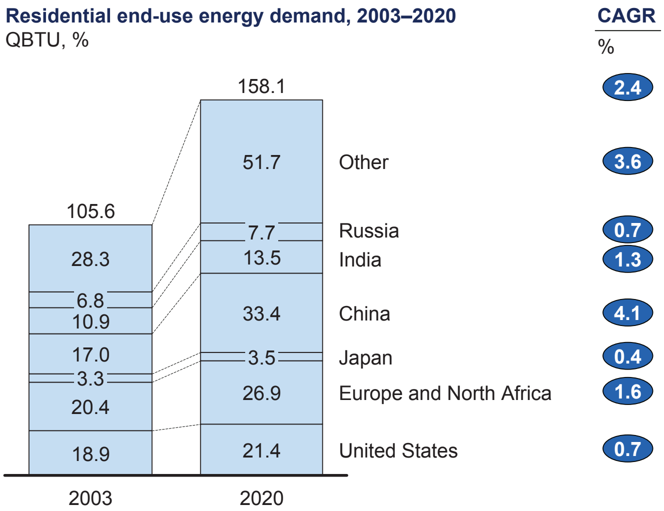
### Growth of energy demand

Growth will explode in China in the coming years, as urbanization and growing wealth in urban areas massively increases residential energy demand. Demand will increase to 33.4 QBTUs by 2020, a 4.1 percent compound annual growth rate (CAGR) (Exhibit 3). In the United States, meanwhile, demand will grow at 0.7 percent per year to 21.4 QBTUs. Demand in Europe and North Africa will expand at 1.6 percent per year, driven largely by the emerging countries of Europe, with the subregions of Baltic and Eastern Europe growing at 2.6 percent and Mediterranean and North Africa growing at 2.3 percent. Northwestern Europe[1] will grow at 0.9 percent per annum. Finally, residential sector demand in India will grow at only 1.3 percent per annum to 2020, significantly slower than in China. This is due to the fact that China already has a strong urban class that will continue to expand its energy usage by buying larger living spaces and more energy-using appliances. India's urban class will only reach the scale of China's in about 15 years.

1 Northwestern Europe includes Belgium, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Switzerland, and the United Kingdom.

## Exhibit 3

**CHINA, UNITED STATES, AND EUROPE DOMINATE RESIDENTIAL ENERGY DEMAND**




Source: MGI Global Energy Demand Model

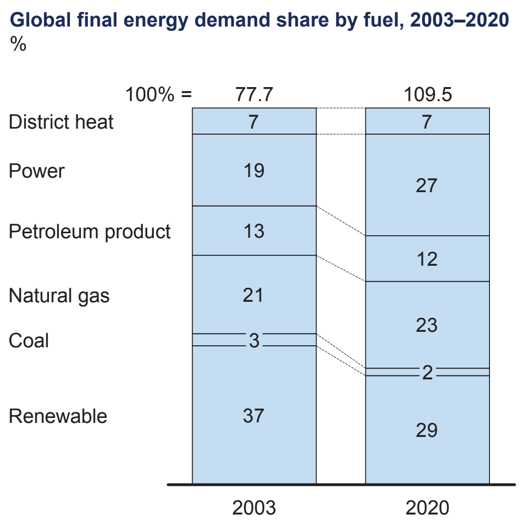
### Sector fuel mix

The largest single fuel in the residential sector, at 37 percent, is biomass (renewables)—the burning of traditional forms of energy such as wood and dung for heat and cooking. This primarily takes place in developing regions, although wood is still used for heat in some developed regions as well (in Northwestern Europe it made up nearly 10 percent of residential energy in 2003). The residential sector will experience one of the biggest fuel-mix shifts of any sector to 2020—with renewables representing only 29 percent of demand by 2020. Meanwhile, power will increase its share from 19 percent in 2003 to 27 percent in 2020 (Exhibit 4). We will see the most dramatic shift in China, where renewables drop from 52 percent to 27 percent and power increases from 17 percent to 38 percent. India also moves radically from 79 percent to 56 percent in renewables, and from 6 percent to 23 percent in power.

Smaller shifts are taking place in other fuels, with coal decreasing its global share from 3 percent to 2 percent, natural gas increasing share from 21 percent to 23 percent, and petroleum products decreasing from 13 percent to 12 percent. However, within different countries, changes may be in different directions. For example, while developed countries such as the United States are decreasing usage of petroleum products in the residential sector (share goes from 12 percent to 9 percent), some developing countries are actually increasing their share—from 12 percent to 17 percent, in the case of India.

**Exhibit 4**

THE RESIDENTIAL SECTOR WILL SEE A LARGE FUEL-MIX SHIFT




Source: MGI Global Energy Demand Model

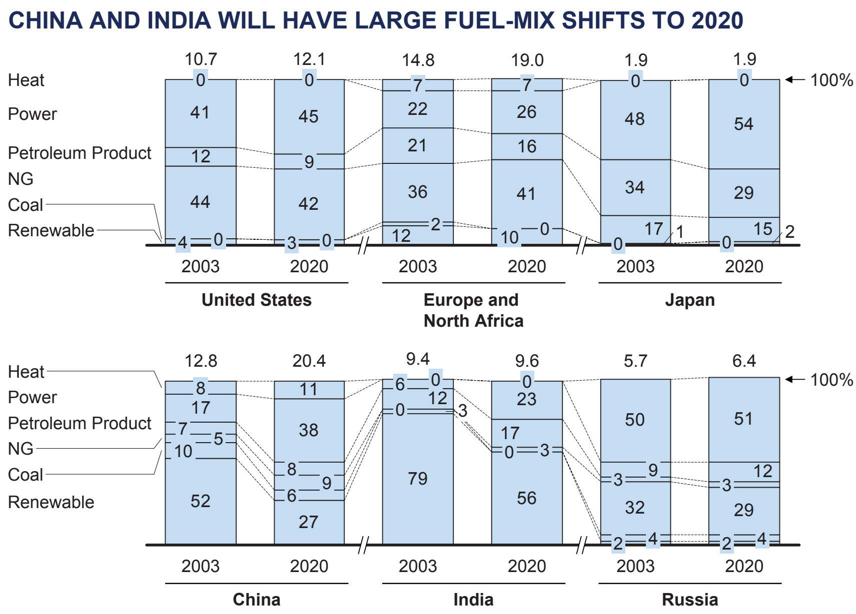
While developed countries will continue to shift toward pipe-transportable natural gas for heating usage, such infrastructure does not reach many urban homes in developing countries. For them, more easily transportable petroleum becomes the fuel of choice. This is especially true in India for two reasons. First, India subsidizes many petroleum products, particularly kerosene and LPG. Second, because India has a warm climate and therefore uses much less fuel for heat (typically only for cooking) than developed countries, installing a natural-gas infrastructure has lower returns compared with buying tanks of LPG for cooking. So while overall demand for petroleum products in the residential sector will change only marginally, its footprint (from developed to developing) and product mix (from heating oil to LPG) will shift more substantially (Exhibit 5).

### $CO_2$ emissions growth by region

The residential sector emitted 4,400 million metric tons of carbon dioxide ($CO_2$) in 2003, growing to 7,500 million metric tons in 2020—a rate of 3.1 percent per annum. The residential share of end-use greenhouse-gas (GHG) emissions is 19 percent, and this will grow to 21 percent by 2020.

The United States represented about one-quarter of residential GHG emissions in 2003, while Europe and North Africa accounted for 22 percent. China emitted about 18 percent of residential GHGs, but this share will grow to 26 percent by 2020. Meanwhile, the United States and Europe and North Africa will fall to 17 percent and 19 percent respectively.

## Exhibit 5




Source: IEA; MGI Global Energy Demand Model

In terms of residential carbon intensity, the United States tops the list in 2003 with 3.8 metric tons of $CO_2$ per capita. Meanwhile, Europe and North Africa emit 1.8 metric tons per capita, and Japan around 1.3 metric tons per capita. While the carbon emissions per capita remain relatively flat in the United States and Japan, those of Europe and North Africa grow at approximately 2 percent per year to 2020, driven by the many developing countries included in this region.

Developing countries have lower residential GHG emissions per capita due to their lower levels of purchasing power and urbanization. Russian currently emits 1.5 metric tons per capita—although we can explain this relatively large sum by the significant amount of heat required in the harsh Russian climate. Meanwhile, Chinese residents emit 0.6 metric tons per capita and those of India 0.3 metric tons per capita. Emissions per capita will double in both India and China to 2020, while Russia's emissions will grow by 23 percent to 1.9 metric tons per capita.

## III. DRIVERS OF ENERGY DEMAND

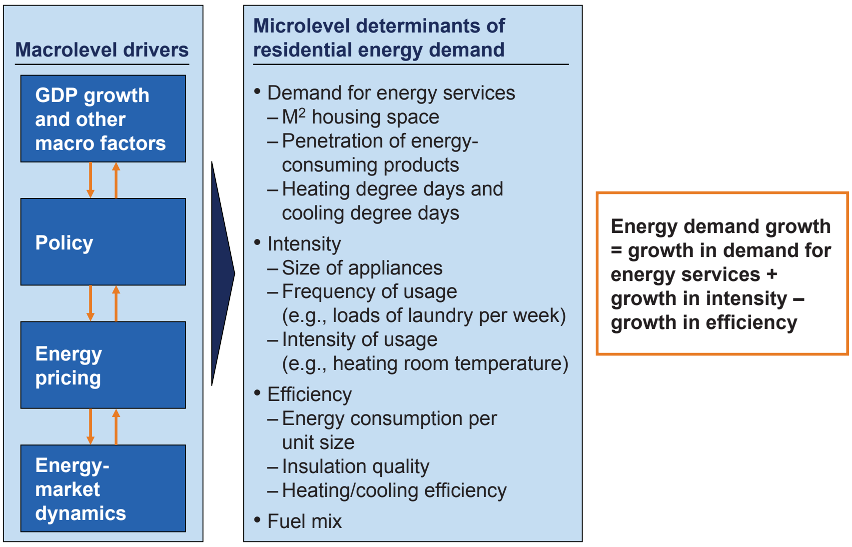
### Case-study methodology and sources

The global residential case is comprised of six country/region studies, with the results being extrapolated across our other 13 regions. The six regions we cover are the United States, the European Union 15 (EU15), Japan, China, India, and Russia. For China and India, we split the countries into rural and urban for modeling purposes, because the characteristics of energy use vary significantly in both amount and fuel mix between urban and rural areas in these countries.

For each country, we tried to construct a historical baseline and then project each of the key drivers of energy demand (Exhibit 6). For the residential sector, the energy demand drivers break down into four categories, and then several subcategories. The four top-level categories are demand for energy services, intensity, efficiency, and fuel mix. These drivers are in turn impacted by a subset of drivers including GDP growth, policies, energy prices, and other market dynamics. We modeled the interaction between the drivers of energy demand and these macrofactors under a base case and several alternative scenarios.

**Exhibit 6**

**MGI'S RESIDENTIAL CASE LINKS MACROLEVEL DRIVERS AND MICROLEVEL RESPONSES**




Source: MGI analysis

For energy-services demand, the key components we projected were the housing stock (measured in square meters—$m^2$) and the penetration of energy-consuming products at the household level. For developed countries, it is the former that drives demand increases; for developing countries, a combination of the two is important. We collected data on historical growth rates of $m^2$ housing and carried out regressions on both in-country time series and also cross-country panel-data comparisons. We did the same for appliances, focusing on the biggest energy consumers including refrigerators, televisions, clothes washers and dryers, and several others.

After understanding the size of dwellings and penetration of appliances, we then moved to intensity and energy efficiency. Efficiency and intensity are often hard to disentangle. For example, the number of kilowatt-hours (kWh) per year for a refrigerator is an aggregate measure that reflects both intensity (liters size of refrigerator) and efficiency (watts per $m^2$). Our first step was to construct an aggregate measure that combined both intensity of usage and efficiency—annual energy consumption per appliance/end use. The key metrics we used were kWh/year (which in turn is calculated by multiplying kWh/hour by hours used) for electricity-using goods; million British thermal units (MBTU)/$m^2$ per heating degree day for heating; kWh/$m^2$ per cooling degree day for cooling; and MBTU/year for cooking and water heating. We collected data from surveys and also triangulated around national statistics for appliance penetration and energy usage per appliance to arrive at intensity figures per residential end-use category for 2003.

By multiplying the aggregate intensity/efficiency measure times the stock of appliances and/or housing space, we obtain an estimate of total energy usage per residential end use. We then add together the residential end usage and obtain the 2003 energy usage per country. This was carefully matched with the 2003 International Energy Agency (IEA) baseline residential energy usage for each country to ensure that our bottom-up model was realistic.

We then proceeded to project both intensity and efficiency to 2020. Intensity was projected forward, again based on understanding how usage might increase through the development cycle—for example, looking at the average number of uses of a washing machine per week and understanding how that might rise as income grew, or how refrigerator size might increase. Input on this phenomenon in developing countries was obtained from Lawrence Berkeley National Laboratories (LBNL). The annual percentage increase in intensity was then projected onto the 2003 aggregate intensity/efficiency measure to 2020.

Efficiency was also projected forward using the same aggregate measure. We relied on three data points to forecast efficiency improvements. First, we looked at the historical experience in each country, looking at how efficiency had improved over the last 10 to 20 years. Second, we obtained reports about the technical and economic energy-efficiency potential for each country (when available), making an assessment of the current energy-policy environment and what percentage of each country's energy-efficiency potential would likely be obtained in such a policy environment. To back up this exercise, we also used data from government agencies such as the Energy Information Agency (EIA) and Japan's Institute for Energy Economics (IEEJ). The annual percentage improvement in efficiency was then applied to the aggregate efficiency/intensity measure to 2020.

Lastly, we needed to project fuel mix. To an extent, we derive our fuel-mix projections directly from the results of our model. For example, urbanization leads to a shift away from biomass and coal and toward fuels such as electricity, natural gas, and petroleum products. Also, to the extent that appliance penetration (which run almost 100 percent on electricity) grows more quickly than $m^2$ of housing space (which drives usage of heating fuels such as natural gas and heating oil), then one tends to see a natural shift to more electricity. Lastly, due to their respective national endowments, countries may naturally gravitate toward certain fuels for heating. For example, Quebec relies heavily on electricity (due to abundant hydropower) while the primary source of heat in the United States is natural gas.

However, there are some fuel-mix shifts that occur because users actually switch their preference or because new infrastructure is installed. For example, India's natural-gas consumption in urban areas will continue to grow as natural-gas service is installed. We took these fuel-mix shifts into account (often based on historical trends but also on national infrastructure plans) in modeling each country.

Once the base case was constructed—starting with the macrofactors and then translating these into their impact on drivers—we then modeled uncertainties and how these would affect energy demand via the drivers. For example, we modeled high- and low-GDP scenarios; high- and low-oil-price scenarios, and changes in energy policy. Section IV below will discuss the results of this exercise.

The main sources of data for each case study were national statistical agencies (Exhibit 7). For the United States, the majority of the data was obtained from the Department of Energy's Energy Information Agency (EIA). For Europe, historical data was taken from Enerdata to form the basis of the projections. For Japan, we used background data from the *Handbook of Energy and Economic Statistics in Japan* produced by the country's Energy and Data Modelling Center (part of the IEEJ). For China, we used data from the LBNL, China's Energy Research Institute, and national statistics. For India and Russia, national statistics provided the bulk of information we used. We used IEA data for the 2003 baseline, as well as the share of energy by residential end use. Other data sources are cited directly in footnotes or in accompanying exhibits where the data is used.

**Floor-space growth**

The first key driver of residential energy demand growth is floor space (Exhibit 8). Floor space affects energy demand mainly because of its impact on the need for space heating and cooling (although energy demand from appliances will also tend to correlate with floor space, it is not the driver as it is with heating and cooling). Floor space per capita varies strongly across countries for a variety

## Exhibit 7

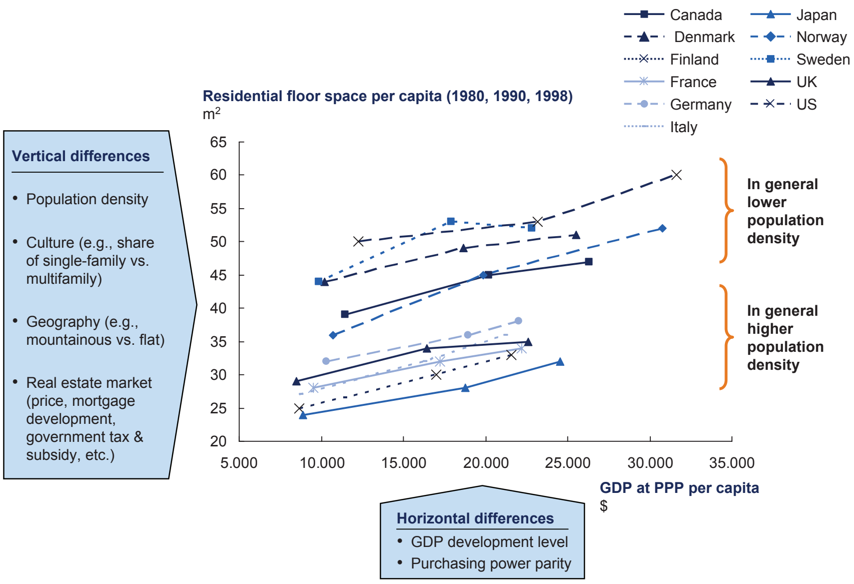
### GLOBAL RESIDENTIAL ENERGY DEMAND MODEL DESCRIPTION

| | Model description |
|---|---|
| **United States** | • EIA residential reference case adjusted so that GDP, fuel price, and efficiency assumptions can be varied |
| **Europe** | • Bottom-up model built based on Enerdata 1990-2004 data for appliance penetration, housing stock, energy-intensity changes, and fuel mix |
| **Japan** | • Built on 1965–2003 historical data from the *Handbook of Energy and Economic Statistics* in Japan from the Energy Data and Modeling Center (EDMC) |
| **China** | • Bottom-up model built from housing stock, appliance penetration, estimated energy intensity, and fuel-mix data; combination of Lawrence Berkeley National Lab, IEA, and Chinese national statistics |
| **India** | • Bottom-up model built from appliance penetration, fuel mix, and electrification data, calibrated to match IEA baseline; data from household survey and national statistics |
| **Russia** | • Bottom-up model built from appliance penetration, fuel mix, and electrification data calibrated to match IEA baseline; data from national statistics |

Source: MGI analysis

## Exhibit 8

### FLOOR SPACE PER CAPITA IS GROWING GLOBALLY AS INCOMES RISE




Source: IEA; MGI analysis

of reasons. Key determinants are GDP per capita, population density, zoning regulations, developments in real-estate market, and cultural differences. The countries with the highest levels of current floor space per capita include the United States, Canada, Denmark, and Finland—all countries with both high per-capita incomes and relatively low population density. Japan and European countries fall into a middle group—while income is high, population density is also very high and this leads to reduced per-capita housing areas. For example, the United States averages 63 $m^2$ of housing floor area per capita, while the EU15 averages 38 $m^2$ and Japan 36 $m^2$. At the lower end of the spectrum are developing countries such as China and Russia, with 25 $m^2$ and 21 $m^2$ per capita respectively. These countries' low $m^2$ per capita can be traced to low levels of development, to an extent to population density, but also to their non-market-based housing-apportion systems.

We project that over the coming 15 years, $m^2$ per capita will converge slightly across countries—with that of developing countries growing most rapidly. China will grow at 2.2 percent per year in rural areas and 2.8 percent per year in urban areas, reaching 40 $m^2$ per capita in rural areas and 35 $m^2$ per capita in urban areas by 2020 (Exhibit 9). While this represents much more rapid growth than in other countries in our sample, it is still significantly slower than the 1990–2005 growth rate of 3.4 percent per annum. In fact, we can discern a distinct shift in the floor-space growth pattern in 1995, when housing privatization started taking off in China. Globally, MGI estimates that housing per capita will grow by 1–3 percent to 2020 (Exhibit 10).

We project Russia's rate of floor-space-per-capita growth at 40 percent of its rate of GDP growth—matching its historical correlation over the past 15 years. However, given that GDP is projected to grow slightly more quickly, floor space per capita should grow at 1.8 percent per annum compared with 1.6 per annum historically.

We project the continued "catch-up" of floor space per capita in both Japan and the EU compared with the United States. Growth in the EU will be some 1.5 percent per annum to 2020, matching the historical rate, while in Japan we expect a slight slowdown from its 1.7 percent per annum growth rate in the 1990s to a rate of 1.4 percent per annum, more typical of the last 25 years.

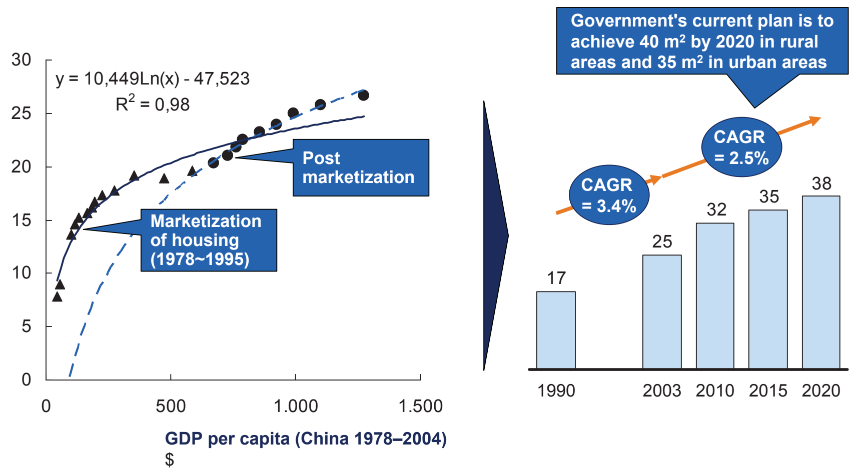
The United States will grow at 1.0 percent per annum, an estimate that we base on the EIA's 2005 projection and also the fact that the United States already features very high levels of floor space per capita.

## Exhibit 9

### CHINA'S FLOOR SPACE PER CAPITA IS EXPECTED TO REACH 38 M² BY 2020

**Floor space per capita has been heavily correlated with GDP growth in China**
Residential floor space per capita

**This trend can be translated into 2.5% growth p.a. in the next 17 years**
m²




Source: WEFA WMM; NSS 2002 data; literature search; MGI analysis

## Exhibit 10

### MGI PROJECTS BETWEEN 1 AND 3 PERCENT M² HOUSING PER CAPITA GROWTH TO 2020

| | Current | CAGR 2005–2020 % | Rationale |
|---|---|---|---|
| United States | 63 | 1.0 | • EIA projection |
| EU | 38 | 1.5 | • Based on historical growth rate |
| Japan | 36 | 1.4 | • Based on slight slowdown from current 1.7% growth rate |
| China | 25* | 2.2-2.8*** | • Based on historical correlation to GDP growth post housing marketization |
| India | N/A | N/A | • M² per capita rate not available; because of no heating and low-cooling penetration, M² per capita not important driver of energy demand |
| Russia | 21** | 1.8 | • Based on historical correlation to GDP growth |

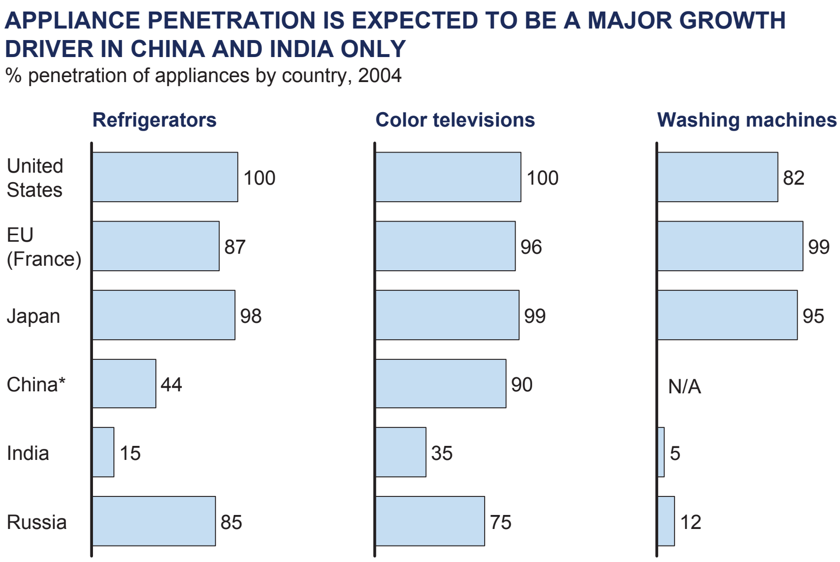
* 2003.
** 2004.
*** Rural = 2.2%, urban = 2.8%.
Source: MGI Global Energy Demand Model

### Penetration of energy-consuming appliances

A second key driver of residential energy services is the stock of energy-consuming appliances owned by households. These include refrigerators, televisions, washing machines, clothes dryers, air conditioners, computers, microwave ovens, and a myriad of small appliances. Most of these appliances use electricity as their energy source—the notable exceptions being clothes dryers and air conditioners, which, at times, use natural gas or other primary fuels.

For basic appliances, developed and even middle-income countries already have a very high rate of penetration. For example, nearly 100 percent of households in the United States and Japan own at least one refrigerator, television set, and clothes washer (Exhibit 11). While one might think these countries have reached "saturation levels" and that further penetration is therefore not likely to drive energy demand, penetration actually continues to grow slowly as households acquire second and even third units of some of these items. This is particularly true for televisions but also for refrigerators. For example, although EU15 households already own 1.1 refrigerators per household and 1.3 televisions, we project that penetration will continue to grow at 0.8 percent per annum for refrigerators and 1.3 percent a year for televisions. Note, however, that this is significantly slower than the projected penetration growth of dishwashers (penetration currently stands at only 42 percent in the EU), which we project to show 2.8 percent annual growth to 2020.

**Exhibit 11**




* China computed from Chinese National Statistics given large variances with Euromonitor data.
Source: Euromonitor; China National Statistics

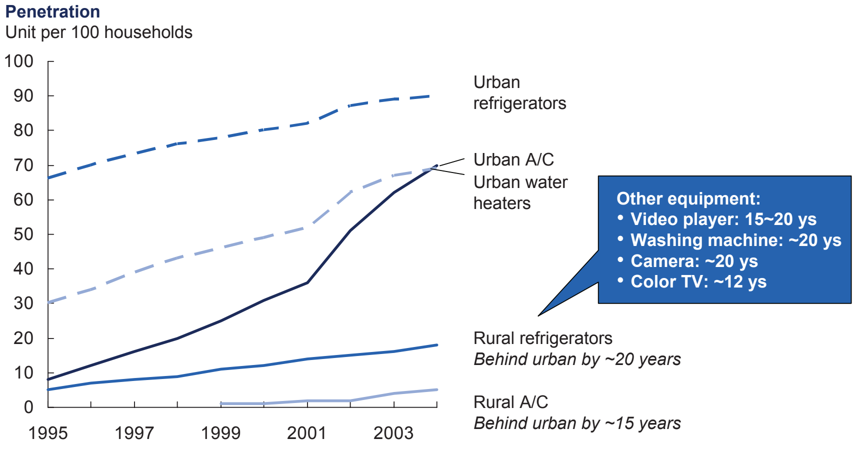
Although penetration growth of major appliances does drive some demand in Japan, the United States, and the EU to 2020, more important penetration growth occurs in the “other appliances” category, which includes a large range of small electricity consumers such as set-top boxes, toasters, audio equipment, and DVD players that continue to proliferate in developed countries. In both Japan and Europe, penetration of these items will grow at nearly 2.0 percent per year.

Penetration of energy-consuming appliances will be a much more important contributor to energy demand growth in developing countries. In China and India penetration of most energy-consuming appliances is below levels common in developed countries, particularly in rural areas. For example, there were 37 refrigerators per 100 Indian urban households in 2002, and only 4 per 100 households in rural areas. In China, the comparable figures were 87 in urban areas and 15 in rural areas (Exhibit 12).

**Exhibit 12**

**PENETRATION IN CHINA'S RURAL AREAS IS STILL SIGNIFICANTLY LOWER THAN IN URBAN AREAS**

**Penetration of major electric equipment in rural areas is behind that of urban areas by approximately 20 years**



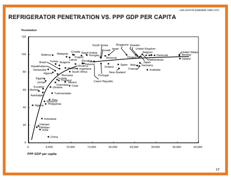

Source: China statistics yearbook; China rural statistics yearbook; MGI analysis

We have projected future penetration growth to 2020 by analyzing cross-section data of appliance-penetration levels’ correlation to PPP GDP per capita (Exhibit 13). We can separate appliances into three groups: necessities, “normal” goods, and luxury items. Each of these groups displays a different type of correlation to PPP GDP per capita. Necessity-goods penetration tends to hit its high-growth phase at early stages of economic development as households tend to buy them at relatively low levels of disposable income; then penetration reaches saturation at moderately low levels of PPP GDP. The two key items in this group are refrigerators and color televisions. Necessities fit best to steep log-curve regressions.

**Exhibit 13**

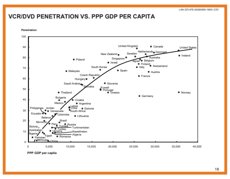
**WE HAVE MODELED FUTURE PENETRATION USING REGRESSIONS OF INTERNATIONAL APPLIANCE PENETRATION VS. PPP GDP/CAPITA**

**Necessities**



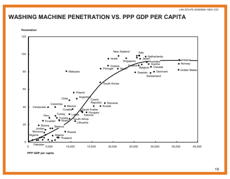

**Steep log-curve**
- Refrigerator
- Color TV

**Normal goods**




**Gradual log-curve or linear**
- Personal computer
- VCR/DVD player
- Vacuum cleaner
- Air conditioner

**Luxury items**




**S-curve/logistic function**
- Microwave oven
- Washing machine
- Dishwasher
- Clothes dryer

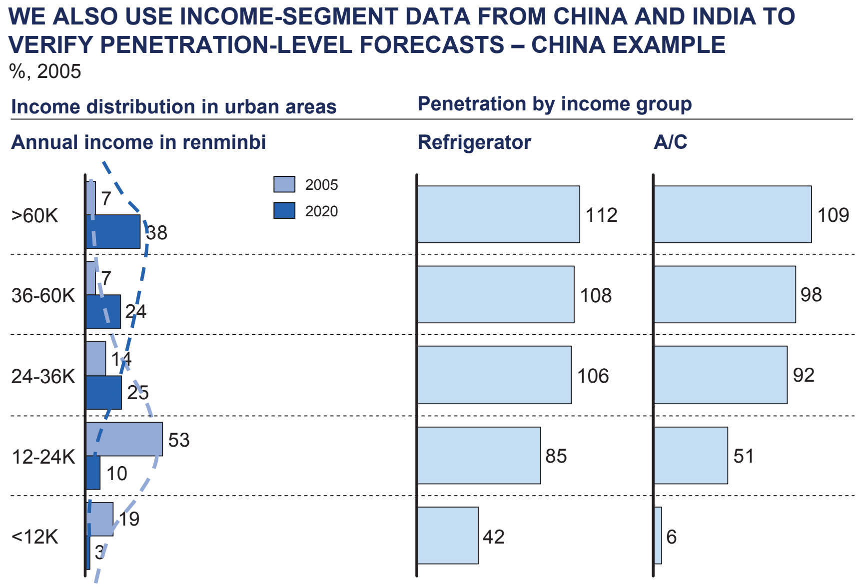
Source: Euromonitor; MGI analysis

Normal goods include such items as personal computers, VCR/DVD players, and vacuum cleaners. These goods tend to follow fairly smooth log curves or even linear patterns, increasing penetration at a relatively similar rate to the growth of PPP GDP per capita. An interesting potential member of this group are air conditioners—while the plot initially seems to show no pattern, once countries with cooler climates are ignored (particularly Europe), then a log-linear regression has a reasonable fit.

The last group is luxury items including microwave ovens, washing machines, dishwashers, and clothes dryers. These items tend to have quite low penetration rates early in the development cycle, and then hit an "inflection point" at a certain rate of PPP GDP per capita (which differs by appliance). These items' penetration is best understood in the well-known "S-shape" or "hockey stick" pattern and we have therefore used a logistic curve to fit the data.

In addition, we used proprietary data from MGI's consumer research in both China and India to triangulate with the GDP-driven estimates of penetration. For example, our surveys show that refrigerator-ownership levels will increase slowly to 2020, based on the fact that near 100 percent penetration has already been reached. Meanwhile, air conditioners—where there is more room for growth—will grow more quickly in urban China (Exhibit 14).

**Exhibit 14**




Source: Asian Demographics; McKinsey China Consumer Center; MGI analysis

Using this type of analysis, we show large jumps in penetration for many appliances in China and India, but slower growth for others. For example, penetration rates for refrigerators are already quite high in China at 87 per 100 households, and will grow at only 1.7 percent per annum. In contrast, however, China's rural areas are yet to go through their rapid phase of penetration growth—at 8.3 percent per annum from 15 per 100 households to 2020. In comparison, in India's urban areas, there are only 37 refrigerators per 100 households, and growth will be 8 percent per annum. At the same time, India has not yet reached the level of income required for washing-machine penetration to take off—even in urban areas—and therefore we see growth of only 3 percent a year to 2020.

### Level of urbanization

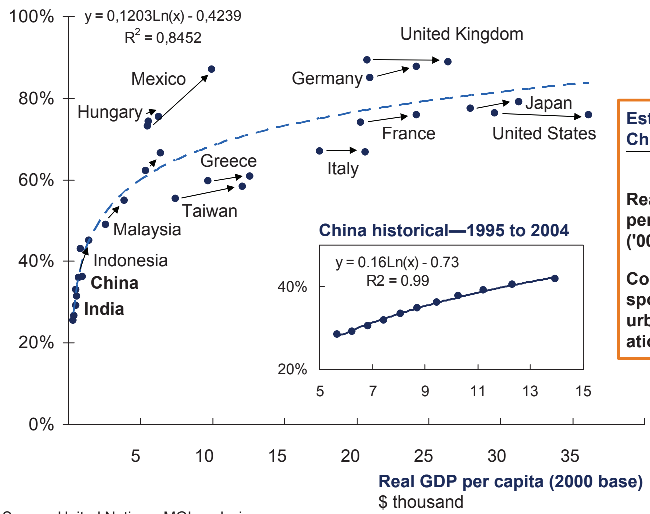
While developed countries have fairly stable levels of urbanization, a strong acceleration of urbanization in China and India will have a significant impact on energy demand. Urban households tend to use energy more intensively and in a different form than in rural areas. For example, penetration levels of air conditioners and refrigerators in China's urban areas are significantly above those in rural areas. In addition, urban areas tend to have access to cleaner fuels such as natural gas, electricity, and LPG, while rural areas use more traditional fuels such as wood and coal.

Urbanization in China has increased by 15 percentage points from 27 percent in 1990 to 42 percent in 2005, and we expect a further 16 percentage-point increase to 58 percent by 2020. As for India, urbanization is set to move 12 percentage points from 34 percent to 46 percent (Exhibit 15).

**Exhibit 15**

**CHINESE AND INDIAN URBANIZATION IS EXPECTED TO FURTHER DRIVE ENERGY DEMAND GROWTH**

**Percentage of urban population—1990 and 2002**




**Estimated urbanization in China**

| | 1990 | 2005 | 2020 |
|---|---|---|---|
| **Real GDP per capita ('000$)** | 0.4 | 1.6 | 5.4 |
| **Corre-sponding urbaniz-ation** | 27% | 42% | 58% |

Source: United Nations; MGI analysis

## Intensity and efficiency

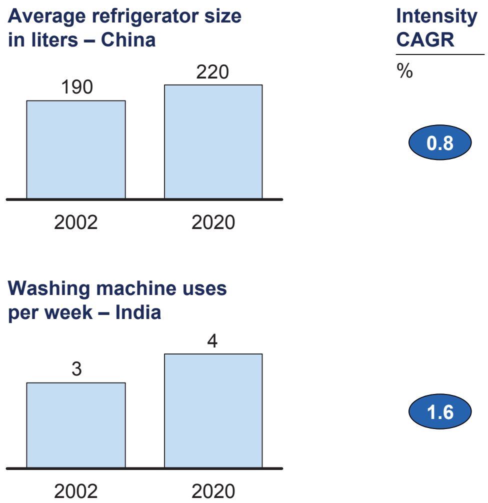
Intensity and efficiency are separate concepts but they are sometimes hard to disaggregate, as we discussed above. Intensity measures how frequently or intensively energy is used—for example, how large is the size of the refrigerator, how many loads of laundry are washed per week, and to what average temperature is the thermostat set? Efficiency then measures the amount of energy required for a given level of intensity—in the examples above, this would be kWh per liter of refrigerator, kWh per load of laundry washed, and MBTU per $m^2$ per heating degree day.

Our primary focus in the residential sector is on understanding the progression of efficiency, rather than intensity. For developed countries, we assume that intensity grows at the same rate that it has over the last 15 years, and then we adjust the rate of efficiency depending on the policy environment in each region on which we are focusing. In China and India, we adjust intensity based on anticipated growth in size of refrigerators, usage of televisions and other appliances, and the intensity of lighting per $m^2$, among other factors.

For example, we assume that, in China, the average refrigerator grows from 190 liters to 220 liters; and that the average washing-machine use in India increases from three uses to four uses per week. These instances represent 0.8 percent and 1.6 percent annual intensity increases respectively (Exhibit 16). We see lighting intensity increasing in both China and India along with household-income growth (Exhibit 17).

**Exhibit 16**

WE PROJECT ENERGY INTENSITY INCREASES IN DEVELOPING COUNTRIES AS THE SIZE OF APPLIANCES GROWS



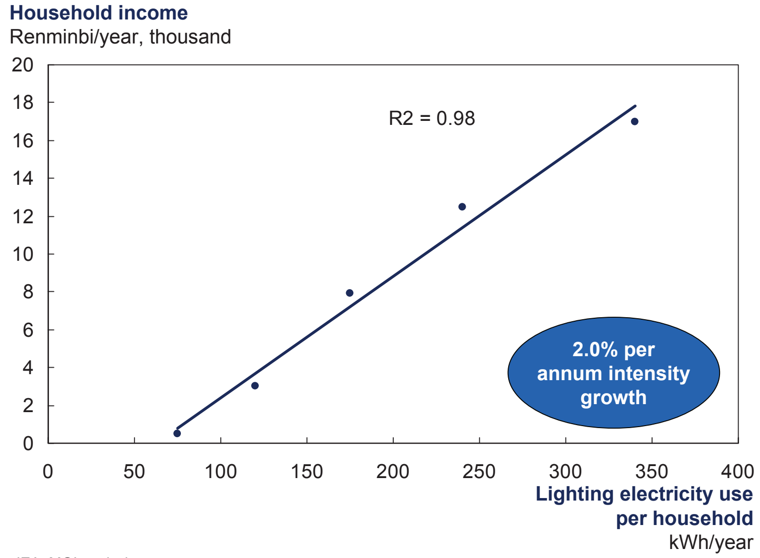

Source: LBNL; MGI analysis

In terms of energy efficiency, we see minimum efficiency standards as the key to capturing the efficiency opportunity. For example, beginning in the 1970s and spearheaded by California, refrigerator efficiency improved in the United States by 4.4 percent per year in 1970–1985 and at a slightly slower rate of 3.4 percent a year in 1985–2000 (Exhibit 18). Similar improvements also occurred in insulation and have the potential to continue across countries (Exhibit 19).

For developed countries, we relied on the projections of local agencies on what level of efficiency improvement they expect to be incentivized by policies that are currently in place; when such estimates were not available, we relied on historical information. It is clear that our assumed efficiency-improvement potential varies across countries (Exhibit 20). In the United States, current policies will come nowhere near capturing the economic potential of more than 20 percent energy-efficiency improvement in the residential sector; we therefore expect a capture rate per year of only 0.2 percent. Japan, which has a rather aggressive

## Exhibit 17

### LIGHTING INTENSITY IN INDIA AND CHINA IS ALSO PROJECTED TO INCREASE WITH HOUSEHOLD-INCOME GROWTH

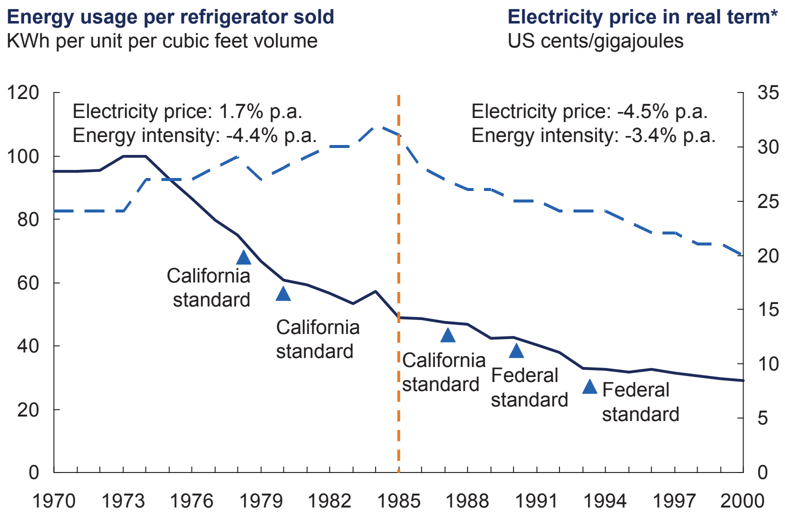



Source: IEA; MGI analysis

## Exhibit 18

### STANDARDS HELPED CAPTURE REFRIGERATOR-EFFICIENCY GAINS

US refrigerator example



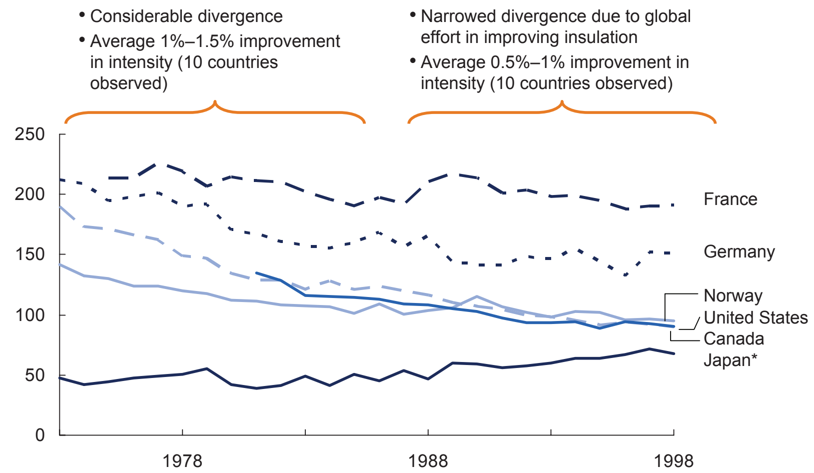

* Base year 1970.

Source: EIA; LBNL; MGI analysis

## Exhibit 19

### INSULATION COULD CONTINUE TO IMPROVE ACROSS COUNTRIES

**Insulation comparison**
measured by kilojoules useful energy/m²/degree day

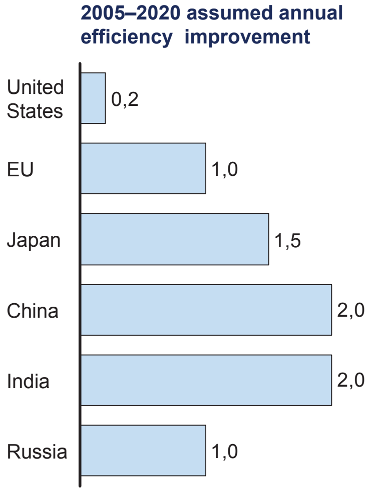



* Low intensity in 1970s in Japan mainly due to low in-house temperature and low heating time; therefore, the effort to improve insulation has been offset by increasing comfort level.
Source: EIA; literature search; MGI analysis

## Exhibit 20

### ASSUMED EFFICIENCY IMPROVEMENT VARIES BY COUNTRY

%




**Rationale**

- EIA base case
- Based on historical performance
- Japan IEEJ
- Based on moderate progress toward China's five-year plan goal of reducing energy intensity by 20% by 2010
- Based on rolling out of state-level DSM programs* similar to those in Kerala, Maharashtra, and Gujarat
- Based on historical EU average rate despite larger opportunity, because of limited policy focus on improved efficiency

* Demand-side-management programs
Source: EIA; IEEJ; China 11th five-year plan; literature search; MGI analysis

"voluntary" standards program (with which all manufacturers comply) called the "Top Runner" program, should do rather better, achieving some 1.5 percent per annum efficiency improvements to 2020 based on current targets (Exhibit 21). The EU lies in the middle, projected to achieve improvements at its historical rate of 1.0 percent a year (Exhibit 22).

**Exhibit 21**

**"TOP RUNNER" STANDARDS CONTINUE TO IMPROVE EFFICIENCY RAPIDLY IN JAPAN'S RESIDENTIAL SECTOR**

| | Target efficiency improvement % | Base year | Target achievement year |
|---|---|---|---|
| Refrigerator | 30 | 1998 | 2004 |
| TV | 17 | 1997 | 2003 |
| Air conditioner | 63 | 1997 | 2004 |

**Projected annual efficiency improvement of 2.0% per annum 2004–10 and 1.4% per annum 2010–20**

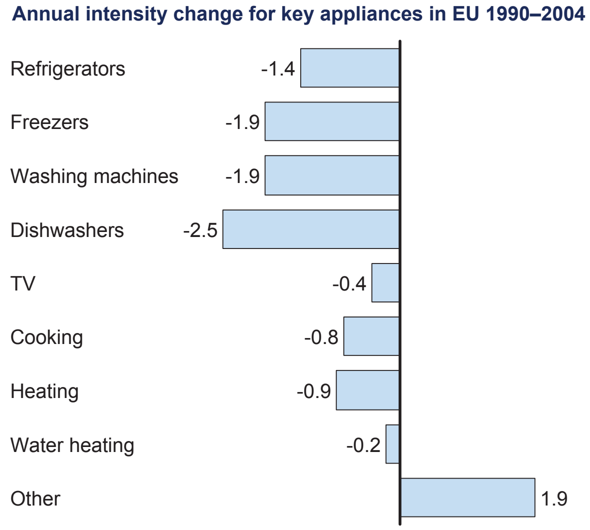
Source: "Japan Long-Term Energy Outlook," IEEJ, June 2006

China, India, and Russia were much more difficult to analyze, as there is a dearth of public information not only on their efficiency potential, but also about the standards (both enactment and enforcement) that they intend to put in place to capture the potential. Given China's fairly aggressive announcement of 20 percent energy intensity targets by 2010—and the fact that there are clearly large opportunities, notably in heating efficiency (Exhibit 23)—we have assumed that China's residential sector achieves a 2.0 percent annual efficiency improvement. We should note that China's 20 percent target implies a much more rapid enhancement of efficiency (Exhibit 24). We believe that there could be the potential to improve efficiency by 3.0 percent or more per annum but it remains our perception that even achieving the 2.0 percent in our base case will take significant effort. India seems to be pushing demand-side-management (DSM) programs at the state level—it is rolling out versions in Kerala, Maharashtra, and Gujarat—and we assume, like China, a 2 percent per annum efficiency capture in India.

## Exhibit 22

### EU HAS ~1 PERCENT PER ANNUM EFFICIENCY POTENTIAL

%

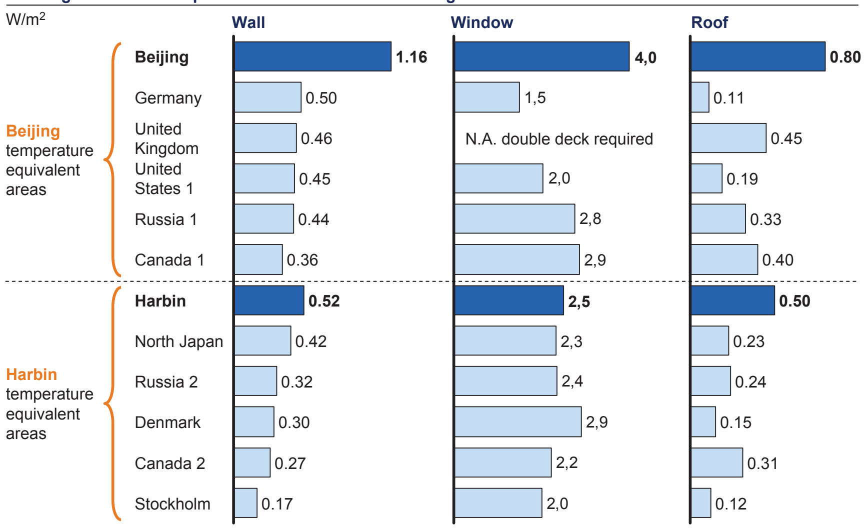



Source: Enerdata; MGI analysis

## Exhibit 23

### CHINA HAS SIGNIFICANT POTENTIAL TO IMPROVE HEATING EFFICIENCY FROM EQUIPMENT AND HEATING CENTRALIZATION

**Building-standards comparison – limitation of heat leakage in wall/window/roof**




Source: ERI; literature search

## Exhibit 24

### CHINA AIMS TO REDUCE ENERGY INTENSITY BY 20 PERCENT BY 2010

| Driving forces | Sectors | Factors | Policies to promote the change |
|---|---|---|---|
| **Social-efficiency change** | • Industry | • Value-added change by subsectors within the sector (as service demand of some subsectors including machinery, other chemical, other mining, other industry sector, etc.)<br>• Products structure change within one sector (as service demand in most industrial sectors) | • Various policies relative to value added such as price policy, national plan for key industry, promote well working market<br>• Market-oriented policies, national development policies |
| | • Residential and commercial | • Energy-activity change within the sector (such as change of use of heating, cooling; use of more efficient electric appliances, etc.) | • Public education, price policies |
| | • Transport | • Change of transport mode (more public transport, nonmobility, etc.)<br>• Traffic-volume conservation (use less private car) | • Transport-development policies, public education |
| **Technology progress** | • For all sectors | • Efficiency progress for technology (unit-energy-use improvement)<br>• Technology-mix change (more advanced technologies)<br>• Fuel-mix change (more renewable energy and nuclear) | • Technology R&D promotion, market-oriented policies, international collaboration<br>• Market-oriented policies, environmental regulation<br>• National energy-industry policies, import and export policies, tax system |

Source: China's 11th five-year plan

Though Russia has clear potential in the area of heating (where customers often pay fixed rates per $m^2$ for heat), there are no clear current plans to tap this opportunity. We have therefore assumed only 1 percent per annum efficiency gains in Russia, in line with the EU (despite the fact that the potential is certainly much larger in the Russia).

### Prices and price elasticity

The price of oil has recently increased dramatically on global markets and one might assume that this would cause a demand reduction in the residential sector. However, the reaction has been, and will continue to be, muted for several reasons. First, petroleum products account for a very small percentage of total direct residential energy needs. Second, residential price fluctuations are dampened on a percentage basis by large distribution costs and taxes in some locations and by subsidies in others. Third, price elasticity in the residential sector is actually quite low, due to the fact that there are many information gaps, principal/agent problems, and other market imperfections that cause users to assign very high return-rate requirements to govern their purchases of higher energy-efficiency equipment. The upshot of all this is that in our $50-oil scenario, there is almost zero demand reduction, and only very small demand reduction is found in our $70-oil scenario (a finding that we discuss further in Section IV). In this section, we discuss each of these factors as well as our assumptions for residential prices by country.

***Fuel share***—The average price of a barrel of oil doubled between 2000 and 2006 and natural-gas prices, which often track petroleum prices, have also fluctuated strongly. However, petroleum products currently only comprise 13 percent of total residential demand; even combined with natural gas, the two represent only one-third of total residential demand. This explains the muted impact on demand from the rise in prices.

***Taxes, distribution costs, and subsidies***—Taxes and distribution costs on one hand, and subsidies on the other, heavily dampen price fluctuations. In the United States, for example, the average natural-gas wellhead price rose by 88 percent in 2001–2005 from $4.00 per MBTU to $7.50 per MBTU. During the same period, residential retail prices rose from $9.60 per MBTU to $12.80 per MBTU—a difference of only 33 percent. The distribution margin remained relatively fixed, rising only 7 percent. Similarly, from early 2002 to early 2006, natural-gas prices for EU15 residential customers rose by only 17 percent. In Japan, natural-gas prices actually *dropped* by 2 percent between 2000 and 2004. Since Japan's residential natural gas is subject to heavy taxes—retail prices are around $30 per MBTU—it is easy to imagine how the residential price can largely be disconnected from the market price.

In our developing-country sample, prices were stable (and will likely continue to be) for a different reason—subsidies. In Russia, many households pay a fixed monthly charge for unlimited supplies of natural-gas as well as district heat (Exhibit 25), completely insulating consumers from global market prices. Consumption patterns therefore do not change despite rising gas prices. In India, high subsidies exist for kerosene and LPG. Indian kerosene prices were only $0.21 a liter in 2005 compared with the residential price of $0.58 a liter in Japan, which neither taxes kerosene heavily nor subsidizes it. Meanwhile, India's LPG prices were only $0.28 per liter compared with $0.75 per liter in the United States. China also subsidized LPG, with prices at $0.34 per liter in 2005 (Exhibit 26).

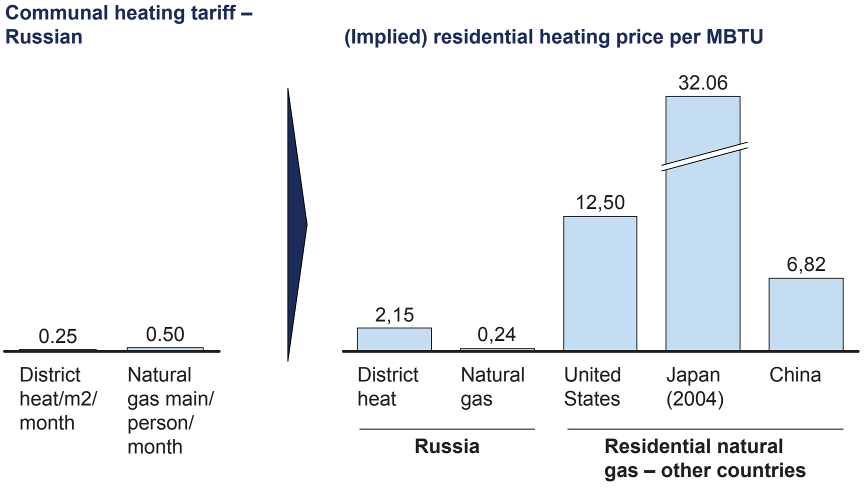
So even if oil prices remain at their current level of $50 a barrel, as we assume in our base case, the impact on residential end-user prices will be quite small.

***Electricity prices***—High distribution margins, taxes, and subsidies also keep electricity prices relatively stable over time. For instance, in India, residential electricity prices are only about $0.04 per KWh, far below the level in areas where prices are set by the market. In the United States, wholesale power prices rose 144 percent in 2002–2005, but residential rates increased by only 11 percent over the same period. Distribution margins as well as slower-reacting rate regulation dampened price movements and we expect this type of dampening to continue to 2020.

## Exhibit 25

### SOME RUSSIAN HEATING IS SUBJECT TO FIXED PRICING; PRICES OF ACTUAL USAGE ARE FAR LOWER THAN OTHER COUNTRIES

$/MBTU, 2005

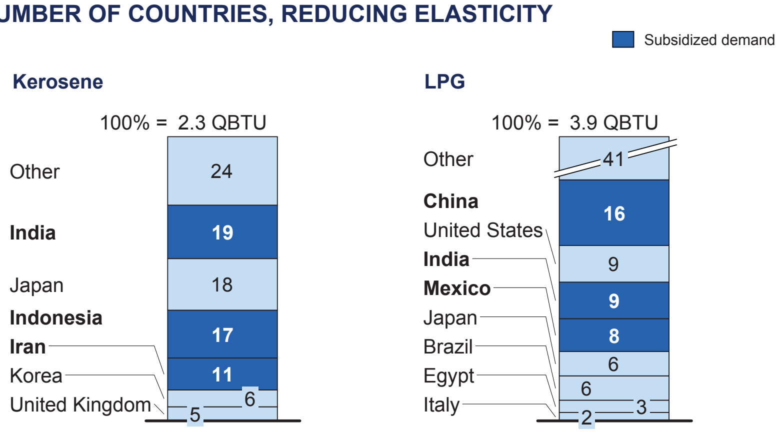



Source: Rosstat; MGI analysis

## Exhibit 26

### RESIDENTIAL LPG AND KEROSENE USAGE AND PRICING IS SUBSIDIZED IN A NUMBER OF COUNTRIES, REDUCING ELASTICITY

%, 2004




**At least 40%–60%* of LPG and kerosene used for residential fuel is sold at subsidized prices**

* 60%+ figure obtained when excluding "other" countries from above analysis.

Source: IEA; literature search; MGI analysis

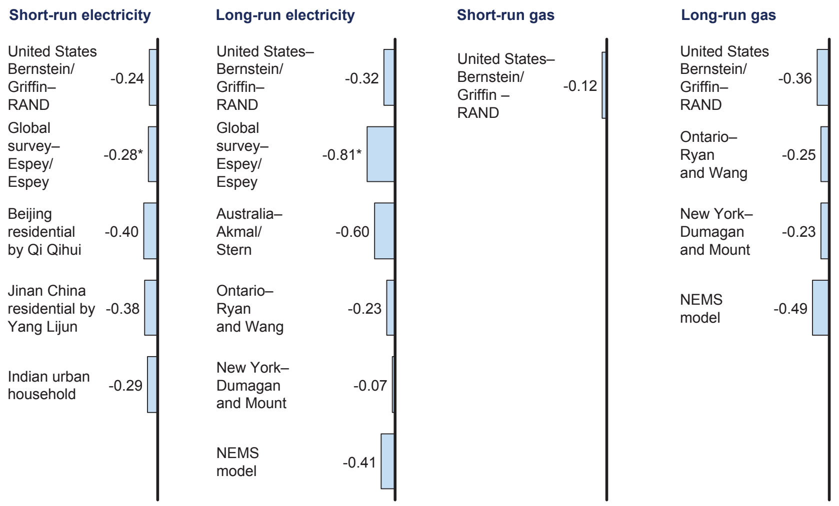
Another important factor dampening electricity-price response is fuel switching. If oil and natural-gas prices stay high in the long run, this will incentivize the building of more coal, nuclear, and renewables plants. Since large price increases in coal and these other forms of generation are not anticipated, this actually provides a natural long-term brake to electricity prices.

For these reasons, our wholesale-price model for the United States and the EU shows relatively stable prices to 2020, even in the $70-oil scenario, the key difference being that less natural gas and oil and more coal are used in higher oil-price scenarios to generate electricity.

***Low residential price elasticity***—Even if prices fluctuate, residential price elasticity is low. Econometric studies of residential price elasticity have shown it to range between minus 0.1 and minus 0.4 in the short run with a slightly higher range in the long run across several residential fuels (Exhibit 27). The key issue for most residential users is that there is no good substitute for the different forms of energy they use. For example, most home appliances—such as refrigerators, televisions, and radios—have no other potential source of power but electricity. In terms of heating their homes, customers theoretically have several choices, including natural gas, electricity, and fuel oil, but switching is often deemed too costly an investment, even in the long run.

**Exhibit 27**

**RESIDENTIAL PRICE ELASTICITY IS LOW IN THE SHORT AND LONG RUN**




* Median of approximately 125 estimates of price elasticity.

Source: Mark A. Bernstein and James Griffin; RAND corporation; "Regional Differences in Price Elasticity of Demand for Energy", James Espey and Molly Espey; "Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities"

Since switching is not an option (or, at best, a very difficult one), residential end users have two main options for reducing energy usage: changing behavior or investing in efficient capital. Initially, there is a choice to change behavior—turn the thermostat down, turn lights off when not in use, use the air conditioner less—and the short-term price elasticity should capture many such opportunities.

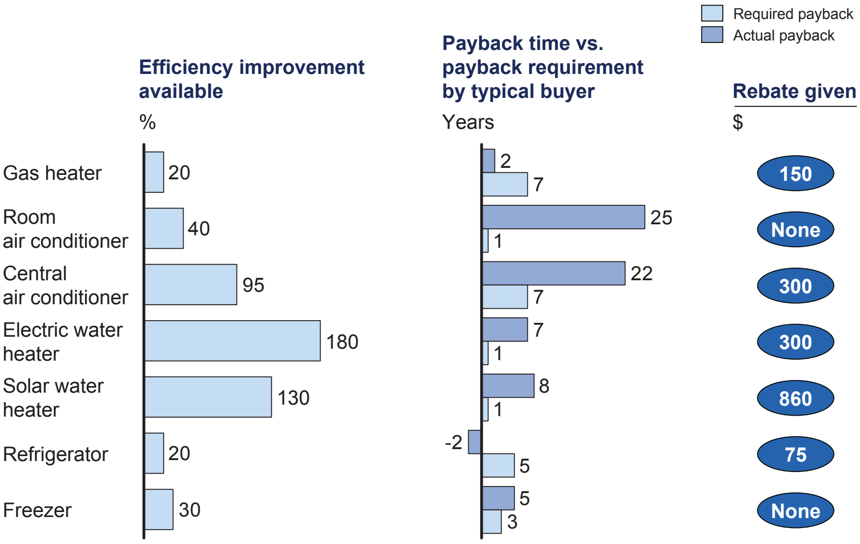
***Capital investment***—In the long term, the main response to high prices would be to install more energy-efficient equipment. However, several barriers mean that this is either a slow process or is unlikely to happen at all. First, many pieces of equipment have extremely long life cycles—refrigerators and water heaters may last 20 years and building shells 100 years or more. Since efficiency economics almost never justify retrofitting an existing working piece of capital with a new one solely to save energy, the installation of more energy-efficient equipment will only occur when old units are retired—and this could take 20 years or more to filter into the entire market. This means that a sustained high price will be necessary to impact consumers' decisions, because they likely establish their future price expectations over a multiyear period.

Furthermore, even when buying replacement capital, end users often do not choose the most efficient equipment, even when it would pay for itself over a reasonable period (a point that we discuss further below). For example, the "average" US residential user requires a one-year payback on any additional capital investment made in a water heater to save operating costs; yet a high-efficiency model delivers a seven-year payback (Exhibit 28). This represents an almost 100 percent return on investment requirement—considerable when one considers that many of the same capital holders would gladly place the same money in the stock market for a 10 percent rate of return. Residential return requirements for energy-efficient capital stock are typically very high for a variety of reasons: principal/agent problems (landlord buys equipment; tenant pays utility bills); lack of consumer value (builders cannot charge high enough prices to justify constructing energy-efficient homes); capital constraints (especially in developing countries); and a lack of information.

Interestingly, the short-term and long-term residential price elasticities are quite similar in many empirical studies, and this appears to confirm our observation that most residential energy-price elasticity is behavioral, rather than based on capital replacement. Our models assume a long-term price elasticity of minus 0.2 for most applications, which is conservative given the evidence we have described. For cooking applications that give users even less scope to change behavior, we assume a price elasticity of only minus 0.1 (Exhibit 29).

## Exhibit 28

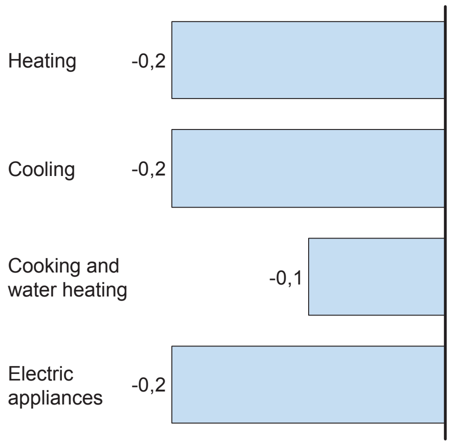
**EFFICIENCY IMPROVEMENT OFTEN DOES NOT MEET US CONSUMER PAYBACK DEMANDS; SO WE USE A LOW PURE-PRICE ELASTICITY**




Source: EIA, MGI analysis

## Exhibit 29

**WE HAVE ASSUMED A CONSERVATIVE PRICE ELASTICITY ACROSS ALL COUNTRIES**




- We choose the low end of elasticity estimates in our model
- None of countries features easy switchability between residential fuels, thus a low elasticity is likely

Source: MGI analysis

## Extrapolating demand to other regions

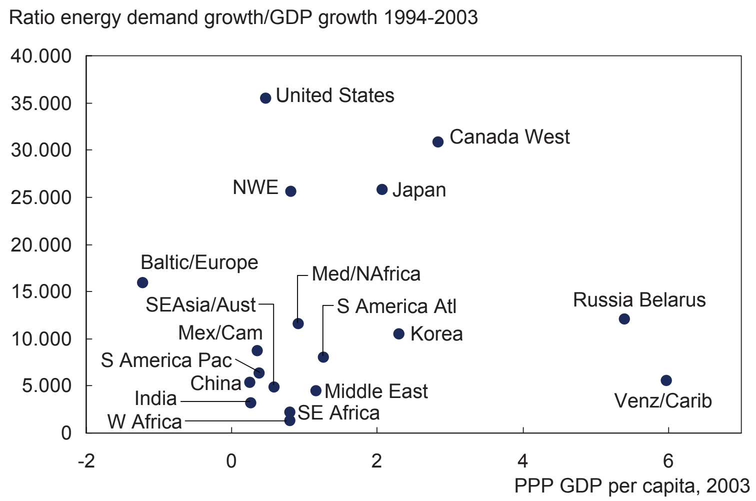
We extrapolated demand to noncore regions using a combination of historical GDP correlations and findings from the bottom-up approach that we applied to those regions we covered in-depth.

Typical correlations of overall residential energy demand growth to GDP growth ranged from 0.6 to 1.0 for most regions in our sample, and we applied this ratio to our GDP-growth projections to obtain overall energy demand growth by region. Unlike in the road-transportation sector, where there is a clear pattern between GDP per capita and the ratio of energy demand growth to GDP growth, no such neat relationship exists for the residential sector (Exhibit 30). For this reason, using the historical relationship was the surest solution. Four regions fell outside the 0.6–1.0 range. On the high side were the Middle East and South American Atlantic regions at 1.2 and 1.3 respectively. At the low end were Central America and Mexico, and South America Pacific, each at 0.4.

**Exhibit 30**

**THE RESIDENTIAL SECTOR DOES NOT SHOW A CONSISTENT TRAJECTORY OF ENERGY DEMAND GROWTH TO GDP GROWTH**

**Ratio of energy demand growth to GDP growth 1994-2003 vs. PPP GDP per capita 2003**




Source: IEA; MGI analysis

Since the R-squared correlations on residential fuel-level growth to GDP growth for most countries was low, we decided to use the case studies as a guide to the expected fuel-mix shifts on a percentage basis over the course of our forecast period. The major movement we identified is from coal and renewables toward electricity, natural gas, and LPG. For example, we project a shift in the share of renewables from 52 percent to 38 percent in the South America Atlantic region in

2003–2020. This is similar, if slightly less dramatic, than China's projected shift from 52 percent to 27 percent renewables over the same period, the difference being that South America Atlantic will not experience as rapid GDP growth and urbanization as will China. We identified and quantified similar fuel-mix shifts across all 13 regions.

## IV. KEY UNCERTAINTIES AROUND THE MGI BASE-CASE SCENARIO

There are four major uncertainties affecting residential energy demand, each with a varying impact: (1) GDP uncertainty; (2) oil- and natural-gas-price uncertainty; (3) the impact of the removal of price subsidies in certain countries; and (4) uncertainty around future energy policy and the capture of energy productivity. In summary, GDP uncertainty swings demand 29 QBTUs between our low- and high-growth case (with our base case being approximately at the midpoint); oil- and natural-gas-price uncertainty swing demand by up to 3 QBTUs between $30 and $70 oil (and corresponding natural-gas prices); the removal of price subsidies in the countries we cover in our case studies (particularly India, China, and Russia) could reduce demand by 3 QBTUs (with the majority coming from removal of the heating subsidy in Russia); and capturing the full energy productivity opportunity would reduce demand by 32 QBTUs in 2020. We now discuss each of these in detail.

### GDP uncertainty

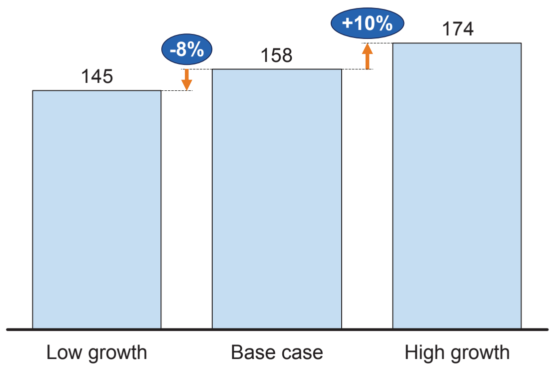
GDP growth rates have a high degree of unpredictability—especially in developing countries—and translate into an uncertainty in residential sector energy demand that is equivalent to 29 QBTUs (Exhibit 31). Our current base-case scenario assumes average real GDP growth of 3.1 percent per annum for the United States, 1.9 percent for developed Europe, 2.7 percent for emerging Europe, and 1.7 percent for Japan. China is projected to grow at 6.7 percent annually, India at 6.1 percent, and Russia at 4.6 percent. The average global growth rate to 2020 is 3.2 percent per annum, which gives us our base-case estimate of residential end-use demand of 158 QBTUs at the end of the period.

The differences between our high- and low-GDP cases are plus or minus 2 percent per annum in China and India; plus or minus 0.5 percent in developed countries; and plus or minus 1 percent in all other emerging regions. The low-GDP-growth case leads to residential end-use demand of 145 QBTUs in 2020, while the high-growth-rate case produces end-use demand of 174 QBTUs. We note that our base case of 3.2 percent global GDP growth uses Global Insight GDP-growth projections, which match the GDP growth rate over the previous 17-year historical period (1986–2003) globally (3.2 percent) but not by region.

**Exhibit 31**

**GDP GROWTH UNCERTAINTY DRIVES APPROXIMATELY 29 QBTUS IN RESIDENTIAL ENERGY DEMAND**

**2020 end-use energy demand under three GDP scenarios**




Source: MGI Global Energy Demand Model

### Price uncertainty

Our scenarios include quite a wide range for oil prices—from $30 to $70 per barrel real price in 2020—with a correspondingly broad spectrum for natural-gas price projections. However, the impact of these different price scenarios on overall demand from the residential sector is minimal for the reasons we have explained.

When retail margins, taxes, and subsidies are taken into account, and our price scenarios are modeled on typical residential consumer-price elasticity, the result is only a 3 QBTU demand difference between our low- and high-price scenarios. No one country stands out for its swing between low- and high-price scenarios, with small moderations or increases seen in many of our regions. The 2 QBTU demand difference can be traced mostly to a deceleration in the growth rate of natural-gas demand, and to an acceleration of the shift away from petroleum products in the residential sector.

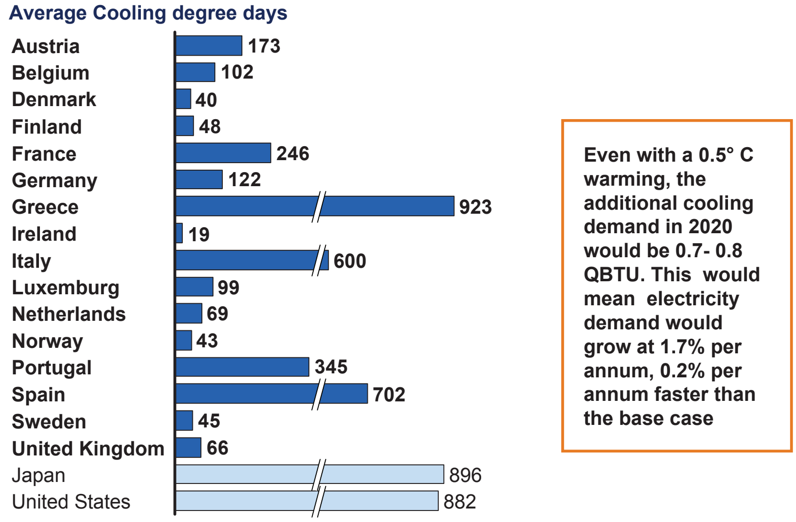
Interestingly, electricity prices are only moderately affected by oil prices in our model. This is because, as oil and natural-gas prices rise, there is a ramping up of coal-build capacity in markets that use both resources to produce power. This long-run shift erodes the pass-through of natural-gas and oil prices to electricity, as we assume coal prices do not fluctuate much over the long term. In the case of electricity, too, end users in the residential sector are sheltered from percentage price movements by large distribution margins, taxes, and subsidies.

### Other uncertainties

It is worth mentioning one other source of uncertainty, which will not have much impact on global energy consumption but is likely to be significant on a country level—air-conditioner penetration. Both Europe and India have very low levels of such penetration. Even if global warming were to raise average temperatures in Europe—and air-conditioner penetration were to increase markedly—cooling degree days would still be low enough to ensure that the number of additional air-conditioner hours would not markedly impact energy demand in the long term (Exhibit 32). The situation in India is different (Exhibit 33). India averages more than 3,000 cooling degree days per year, and has less than 1 percent national air-conditioner penetration. Other "hot countries" such as Nigeria, Pakistan, and Thailand all have more than 10 percent air-conditioner penetration. Should India enter a "catch-up" phase of penetration to 2020, overall residential electricity demand growth would increase substantially by 0.7–1.5 percent per year. This is in addition to an already robust 8.7 percent annual growth rate assumed to 2020, due to increasing electrification in India (with substantial substitution from kerosene lighting to electric lighting in rural areas). This would mean a 90–180 TWh increase in electricity demand in 2020 (Exhibit 34).

**Exhibit 32**

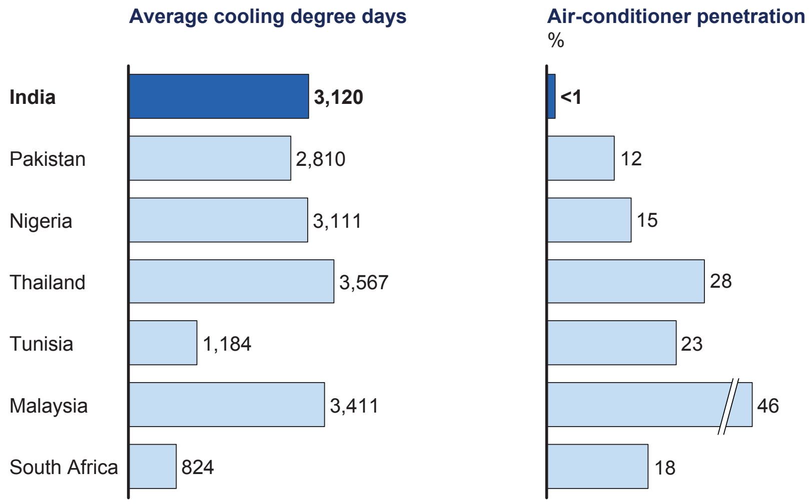
**INCREASED PENETRATION OF AIR CONDITIONERS IN EU15 RESIDENTIAL SECTOR WILL NOT STRONGLY AFFECT DEMAND***




* Assumes US cooling intensity of ~40 Btu/M2/CDD; assumes 40% penetration of air conditioners by 2020.
Source: World Resources Institute (WRI)

## Exhibit 33

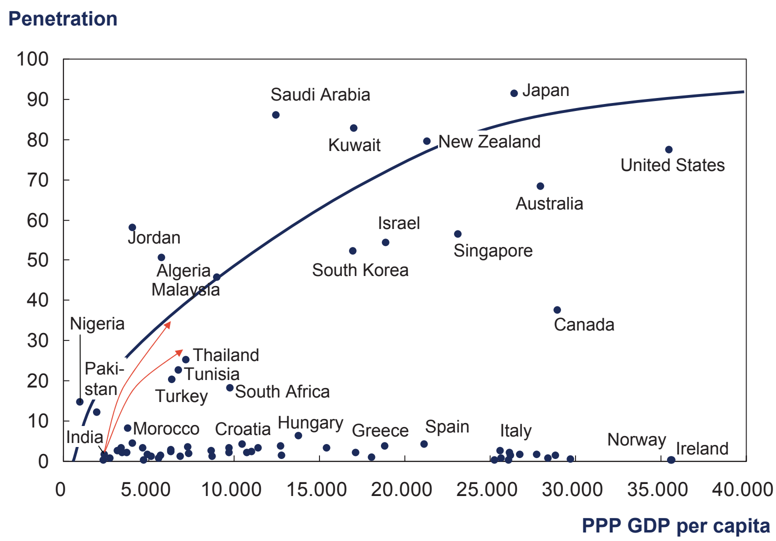
### INDIA HAS A VERY HOT CLIMATE AND VERY LOW AIR-CONDITIONER PENETRATION




Source: WRI; Euromonitor

## Exhibit 34

### AIR-CONDITIONER PENETRATION VS. PPP GDP PER CAPITA – 2004




Source: Euromonitor; MGI analysis

Two reasons air conditioners have low penetration in India are their high operating costs and the unreliable electricity infrastructure service that is more likely to black out under the heavy demand load of air conditioners. As the government builds on the electricity network, it would be prudent to consider the extra load that normal levels of air-conditioner penetration for India's GDP per capita will imply.

## V. ENERGY PRODUCTIVITY OPPORTUNITY

While high energy prices lead to some energy demand reduction in many global end-use sectors, they only mildly reduce that of the residential sector because of an array of market imperfections including principal/agent problems, lack of information, capital constraints, and high discount rates on investment in energy-efficient equipment that deter both manufacturers and end users from capturing many positive-IRR energy-efficient investments.

### Barriers to higher energy productivity

Three major market imperfections are found in the residential sector: principal/agent problems, lack of information, and capital constraints. Principal/agent issues emerge in owner-renter situations where owners pay for much of the building shell and energy-using equipment (HVAC, major appliances) while renters pay the utility bill. In practice, owners have little incentive to make energy-efficiency investments, as they often do not reap the savings from the equipment. In the United States, around half of residential dwellings are renter-occupied, while in Japan that number is around 40 percent, and in Europe it ranges from 10 percent to 60 percent.

The problem of lack of information stems from the fact that utility bills are affected by multiple factors, making it difficult to compare bills (and understand savings) from one house to the next, or from one month to the next. For example, one might install compact fluorescent lightbulbs in the same month in which abnormally high temperatures occurred, necessitating greater air-conditioning usage. While there may have been savings on the lighting component of the bill, the increased usage of air-conditioning will make these savings hard to discern. This also complicates principal/agent issues, since it then makes it hard to verify the actual amount of energy expense (as preferences may change the demand for energy services from one tenant to the next).

Lastly, capital constraints can come into play. The reason for this in developing countries is obvious because in such regions capital is scarcer and financial systems are often underdeveloped. However, capital constraints may also be a factor in developed countries. For example, homeowners who qualify for a maximum mortgage amount may choose to trade off potential energy-saving technologies for amenities and square footage. This gives builders the incentive to build homes that maximize the amenities and square footage components of their price tag, even if energy productivity opportunities are available.

### Capturing the energy productivity opportunity

Countries vary in their projected capture of the energy productivity opportunity, but all have the potential to capture more than projected in our base-case scenario, which assumes current policies will continue. There are significant investments in the residential sector, which we outline in this section, which would yield a 10 percent or more internal rate of return (IRR) while improving energy efficiency. We classify such opportunities as ones that will increase the energy productivity of the economy. These opportunities are based on new-equipment purchase or new builds, rather than on retrofit economics (although some building shell retrofit opportunities may exist for older houses). For all of our IRR analysis, we rely on data made available to us by the EIA, on the current prices and efficiency levels of residential energy-efficiency equipment and typical household energy usage per appliance per year (across various US climatic regions). We then extrapolate the energy productivity opportunity for the United States by considering the capital-stock turnover to 2020 for each category. Next, we extrapolate to other regions by making an assessment of the current difference between the US efficiency level and other regions' efficiency levels.[2] Lastly, we size the total untapped energy productivity opportunity by subtracting that part of the opportunity that will be captured with existing policies.

The equipment opportunity falls into five categories: heating and cooling package (including building shell); lighting; water heating; major appliances; and small-appliance standby power (Exhibit 35). We now discuss each of these in turn:

- **Heating and cooling package** is one of the largest areas of opportunity, particularly in new-housing builds. We used simulations by the EIA that compared the installation of heating and cooling packages that only just met the standard with 30 percent, 40 percent, and 50 percent improved efficiency packages. These simulations were conducted across various house types (manufactured homes, single-family homes, and multifamily dwellings) and a number of cities (including Chicago, Boston, New York, Las Vegas, and

2 We chose to use benchmark data from the US residential sector not because it is the benchmark for energy productivity, but because it has the most publicly available microlevel data on household-level energy usage. In fact, depending on the residential equipment category, one of several regions including the United States, Europe, and Japan may have the most stringent efficiency standard.

Fresno, California). Both heating and cooling savings were considered. Take as a base-case illustration the example of a 2,500-square-foot, single-family house in Iowa City that includes R-28 roof insulation, R-14 wall insulation, R-13 floor insulation, 0.46 U-factor windows, and a heat pump with a 6.8 heating seasonal performance factor (HSPF) and a 10 seasonal energy efficiency rating (SEER). In a 50 percent more efficient house, the corresponding values are R-60 roof insulation, R-21 wall insulation, R-25 floor insulation, 0.33 U-factor windows, and a 10.6 HSPF/18.6 SEER heat pump. To achieve this 50 percent gain in efficiency, the additional investment needed is approximately $3,500 for estimated annual energy savings of some $400, on the basis of current energy prices. This just meets the 10 percent IRR benchmark, delivering a 12 percent IRR. We considered a total of 12 simulations with an average IRR of 18.8 percent in the 40 percent savings case, and 9.3 percent in the 50 percent savings case.

**Exhibit 35**

LARGE ENERGY-EFFICIENCY OPPORTUNITIES EXIST IN DEVELOPED COUNTRIES

| | % of opportunity | IRR<br>% | Description |
|---|---|---|---|
| **Heating and cooling package** | • 50 (new builds)<br>• 25 (replacement) | • ~10<br>• ~10 | • Based only on current technology<br>• Shell improvement assumed only for new buildings |
| **Lighting** | • 65 | • 100+ | • Compact fluorescent lighting |
| **Water heating** | • 65 | • 11 | • High-efficiency electric water heater<br>• Solar water heater |
| **Major appliances** | • 40-60* | • N/A (may be ∞) | • Increasing appliance efficiency standards at 2–3% per year |
| **Small appliance standby** | • 40 | • N/A (may be ∞) | • Reduce standby power requirements of televisions, set-top boxes, etc. |

* Based on future improvements.
Source: EIA; literature search; MGI analysis

- **Lighting** offers a major opportunity for savings. There are very clear and well-known benefits to installing compact fluorescent lightbulbs: the average savings over incandescent bulbs is about 66 percent, which represents an IRR of more than 100 percent (partly achieved because compact fluorescent lightbulbs last up to eight times as long as the typical incandescent bulb).

- **Water heaters** are another area of opportunity. Demand-instantaneous water heaters, which heat water as it is used, save significant energy compared with the common tank-based systems used in the United States, as they do not incur the standby loss associated with the 20–80 gallons of water usually held in a typical American water-heating tank. Demand-instantaneous water heaters can therefore save up to 65 percent of the energy used in water heating, with a calculated IRR of around 11 percent. There are some caveats to the installation of such heaters—they may not work in cases in which very large volumes of hot water are needed instantaneously, and retrofit may be difficult. Solar water heaters are another option with even higher energy-saving potential than demand electric water heaters. However, the IRR on these heaters is currently below 10 percent without tax credits (when a US tax credit of $800 is included, the IRR is slightly above 10 percent), and this may not be economic compared with installing a high-efficiency gas heater.

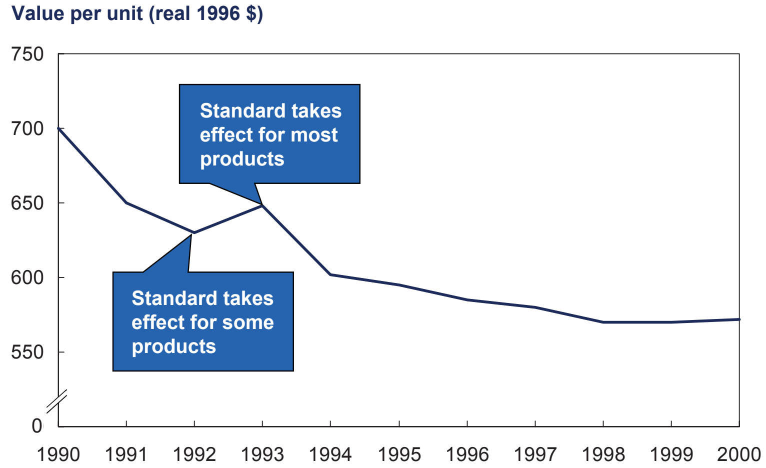
- **Large appliances** are a slightly more complex energy-savings story. The vast majority of large appliances manufactured and sold in the United States meet (but do not go above) the current government standard for efficiency. Virtually without exception, existing high-efficiency equipment fails to meet a 10 percent IRR requirement, because such appliances sell at a large premium to standard units. For example, a room air conditioner that is 35 percent more efficient than the current standard costs 260 percent more—giving a substantially negative IRR. However, studies have shown that when new standards are implemented, economies of scale in manufacturing, and therefore the ability to cut costs, tend to result in the price moving relatively quickly to the price of the less-efficient equipment under the previous standard. Steven Nadel[3] shows this dynamic at work in the recent case of residential air-conditioner standards implemented in the United States in 1992–1993 (Exhibit 36). Although prices per unit briefly moved upward, by 1994 they had resumed their pre-1992 downward trend. Anecdotal evidence from the same paper indicates that the same pattern occurred after the implementation of most recent US refrigerator standards and also in the case of new appliance standards introduced in Europe. There are several reasons for the downward adjustment in price: not only do manufacturers take advantage of economies of scale, but they also tend to use the introduction of a new standard as an opportunity to reduce production costs. Since many large appliances have increased efficiency by 2 percent per year since the 1980s—with prices generally declining over this period—we believe that standards could be used

3 Steven Nadel, "Appliance and Equipment Efficiency Standards," *Annual Review of Energy and Environment*, 2002:27, p. 159–192.

to reinforce this trend and ensure a positive IRR to the consumer. An even higher rate of improvement (around 3 percent per year) should be available in developing countries such as China and India where current standards are less stringent. Overall, we see a potential of 40 to 60 percent improvement in this category to 2020.

**Exhibit 36**

**DESPITE TOUGHENING OF US AIR-CONDITIONER STANDARDS, CONSUMER PRICES CONTINUED TO DECLINE**




Source: Steve Nadel, "Appliance and equipment efficiency standards"; *Annual Review of Energy and the Environment 2002-2*, p. 159–197

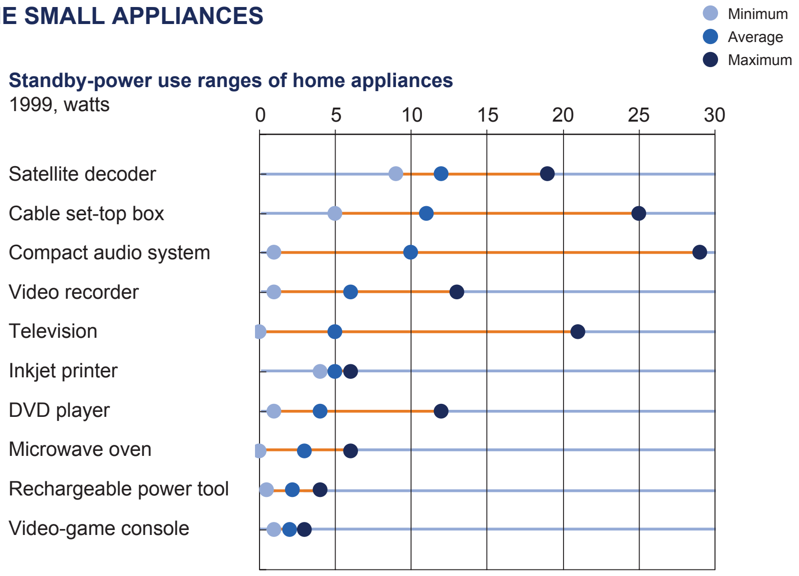
- **Small appliances** individually consume a modest amount of energy; collectively, however, they use a great deal and represent around 10 percent of overall residential energy consumption. Furthermore, they are the fastest-growing segment in developed countries. One key way to improve their energy efficiency is to reduce standby-power requirements. Even when appliances such as set-top boxes are in the "off" mode, they consume standby power (the only way to truly reduce power consumption to zero is by completely unplugging the device). Standby-power consumption in developed countries ranges from 20 to 60 watts, equal to 4 percent to 10 percent of residential power consumption (Exhibit 37). In China, a recent study of standby-power usage in Guangzhou showed average usage at 37 watts, representing up to 16 percent of total winter residential power consumption. If extrapolated across China, standby-power usage could total as much as 25 TWh of power a year.[4] However, with good design, the standby power of most devices can be

4 Jiang Lin, "A Trickle Turns into a Flood: Standby Power Losses in China," Lawrence Berkeley National Laboratory Draft Paper, December 2002.

reduced to one watt or less. Alan Meier, a leading researcher on this subject, calculates that standby-power consumption could be reduced by up to 72 percent with perhaps even more potential in developing countries.[5]

**Exhibit 37**

**STANDBY-POWER REQUIREMENTS CAN BE AS HIGH AS 30 WATTS FOR SOME SMALL APPLIANCES**




Source: *The Economist*; LBNL

Capturing the potential in all five categories that we have described requires the installation of new capital equipment, and since consumers are not inclined to replace working equipment with new more energy-efficient equipment, a key driver of additional energy productivity capture will be the turnover of the capital stock.

For small appliances and lighting, lifetimes are shorter than the 17-year time frame of our analysis. We consider that the "regulatory time period" is effectively only about 12 years—starting in 2008 (as 2003–2006 are passed from a historical standpoint but not a data standpoint). Therefore, nearly 100 percent of the capital stock of these devices should be less than 12 years old in 2020 and therefore, theoretically, 100 percent of the energy productivity opportunity could be captured in these segments.

For water heaters, large appliances, and heating and cooling equipment, the effective life according to EIA data ranges from 5 to 30 years. Using a simulated vintage model that assumes that refrigerators have an effective life of 7 to 26 years, and an equal number of refrigerators from each vintage retire in t+7,

5 Excerpted from "Pulling the Plug on Standby Power," *The Economist*, March 9, 2006.

t+8, t+26, etc., we find that approximately 75 percent of the 2020 refrigerator capital stock will fall into our effective regulatory period of 2008–2020. We also assume 2 percent sales growth for refrigerators, a rate that might be typical for developed countries. Developing countries will have a much higher rate of sales growth, reflecting more rapidly increasing penetration, and the "regulatory-effective stock" should be 85 percent to 90 percent by 2020. Thus, most of the opportunity for this segment could also be captured in both developing and developed countries.

For building shells, capital-stock turnover is much slower. The rate of retirement of housing is extremely low in developed countries and this means that much of the new capital stock actually comes from growth in overall floor space via new builds. Using the new floor-space-growth projections we have highlighted, combined with a 1 percent annual retirement rate in China and India and some 0.33 percent in developed countries, we estimate that the new housing stock in 2020 will be 20 percent in developed countries and 40 percent to 50 percent in developing countries.

End-use savings by type are translated into overall savings by combining the percentage share of each end use. We used data from IEA, LBNL, and several national statistical sources to understand current energy usage by end-use equipment time. Countries vary markedly in this respect, depending mostly on their stage of development and climate. For example, in Russia, 75 percent of residential energy demand is used for heating. In China, 35 percent of end-use residential sector demand was used for space heating, while India used virtually none (Exhibit 38).

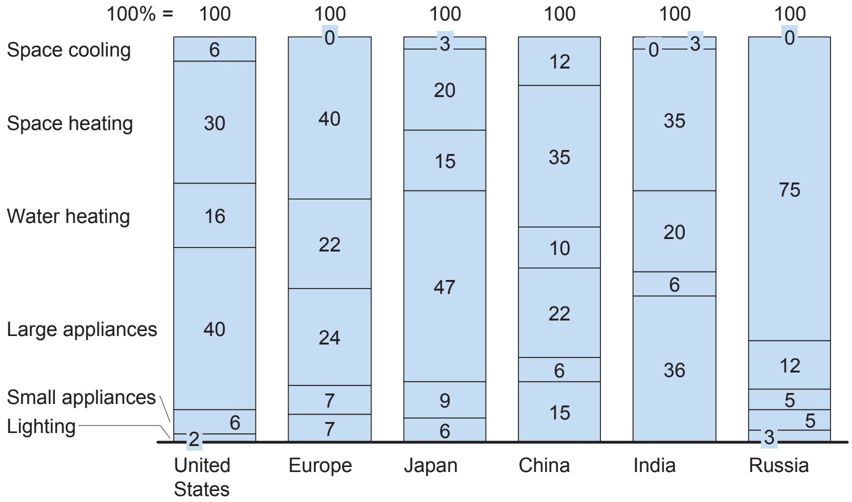
Large appliances—such as refrigerators, washing machines, dryers, and dish-washers—dominate developed-country appliance usage, representing 47 percent of residential usage in Japan, 40 percent in the United States, and 24 percent in Europe. Thus, improving shell efficiency turns out to be a key factor in developing countries (especially Russia), while increasing appliance efficiency (including the reduction of standby losses) is quite important in developed countries.

To estimate the total energy savings in the residential segment, we split devel-oped and developing countries. We then multiply the percent savings by end-use segment (detailed in the first part of this section) times the new capital stock per end-use segment (detailed in the second part of this section) and then calculate the weighted average savings using the percent share of each end-use equip-ment segment (detailed in the third part of this section). By doing so, we obtain a weighted average energy productivity potential of 30 percent in developed countries and 45 percent in developing countries in the nonrenewables portion of energy demand (we do not recognize any energy productivity opportunity in renewables). This translates to a 2 percent per annum improvement from 2008 to 2020 in developed countries and 3 percent per annum in developing countries.

**Exhibit 38**

**SHARE OF END-USE DEMAND VARIES MARKEDLY BY COUNTRY**

**Share of energy demand by end use, 2003**
%




Source: LBNL; IEA; MGI analysis

As we have noted, current policy will already lead to capture of some of this potential If we subtract this, we estimate that 32 QBTUs of energy productivity potential will not be captured by already implemented or planned policy. This represents an additional opportunity of 21 percent of global residential energy demand, equivalent to 26 percent of nonrenewables energy demand.

### Policies to overcome these barriers

It is important to note that the residential sector is the single largest energy consumer worldwide, and also the one where the largest uncaptured positive IRR opportunity exists. Governments vary in their aggressiveness in energy-efficiency policy but the fact remains that every country we analyzed in detail can capture even more energy efficiency than current policy will accomplish. By enacting policy to capture more of the available—and economic—energy productivity opportunity, policy makers have the opportunity to simultaneously improve energy security, increase economic growth, and enhance environmental quality. As we have described, the residential sector responds much more readily to standards than to taxes due to its low price elasticity. Therefore, the key to capturing more energy productivity opportunities is to increase mandates more rapidly and enforce them more aggressively.

The total investment required to capture the energy productivity opportunity is not inordinately high. For instance, in the United States, we calculate that the annual investment required to capture the heating and air-conditioning opportunity (including building shell) would be approximately $10 billion per year, while the water-heating opportunity would cost another $10 billion to $15 billion per year. The lighting opportunity would entail a one-time cost of about $10 billion in addition. These investments would all be made at the household level. We have used the United States as an example here; other countries such as China would likely have a higher annual investment requirement (even on a per-capita basis) due to the fact that the capital stock is growing more quickly and that current standards are lower.

Investment would also need to come from manufacturers of appliances to upgrade their plants to produce more efficient equipment in scale (for which the technology is largely already available), and also to produce future appliance-efficiency gains beyond those that already exist. For example, Carrier invested $250 million for the launch of its 13 SEER air conditioner in the United States. Our rough estimate is that it cost all US appliance makers $2 billion to $3 billion on this launch. If we assume that there will be one or two new appliance standards per year (on a rotating basis), this would imply an additional $5 billion of investment. One should note, however, that, if standards were more global and therefore global scale could be achieved, this amount could be spread across more countries (as opposed to the household investment, which scales out according to the number of households). In addition, some of this investment may be covered through higher prices initially (although, as we have noted, prices for new, more efficient appliances tend to decline quickly).

**Appliance standards and building codes** are worth considering first. A 1 to 2 percent annual improvement in standards in most countries is feasible. Legislation and enforcement to back up the target will be needed, as well as a timeline for any change in standard that is sufficient—say, five to seven years—to allow manufacturers the time to recover their investments. We estimate that implementing appliance standards would capture about 60 percent of the opportunity in developed countries and 40 percent in developing countries.

Building standards could be raised on a similar schedule. It remains the case that if more aggressive standards were to be implemented now, more of the significant energy productivity improvement opportunities that are already available could be tapped. Adjusting building standards would, we believe, capture more than half the opportunity in developing countries and 20 percent to 25 percent in developed countries.

Compact fluorescent lighting (CFL) could be mandated (as Australia has recently legislated); or programs by utilities could be subsidized to encourage their increased penetration. If CFL reached 100 percent penetration, 5 to 10 percent of the energy productivity opportunity would be captured.

Standby-power requirements could be regulated and reduced in all countries. For most items, 1-watt standby power has been shown to be feasible and it would not be difficult to make this the global standard. This would capture about 5 percent of the total residential energy productivity opportunity.

**DSM programs** are, aside from standards and regulation, an effective tool to motivate utilities to reduce energy demand, instead of always striving to meet demand growth through new supply. These programs are common at the state level in the United States and are also gaining popularity in other places such as India. Utilities can increasingly use technology such as broadband over power lines to help residential customers better understand and reduce their energy usage, which can be a key plank of DSM programs in the future. Once utility bills can be disaggregated into their components, more interesting financing options for energy efficiency investments that have a positive net present value may also become viable for utilities. Because currently all usage is lumped into one bill, it is difficult to understand and therefore quantify the benefits of a single piece of new energy-efficient equipment and correspondingly hard for an outside party to fund the upfront investment in return for a share of the savings.

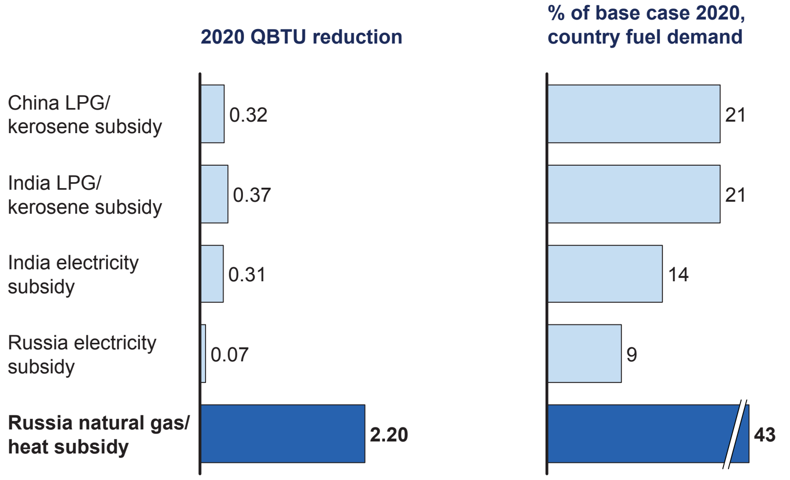
**Nonutility private-sector players** could also take a role in improving residential energy productivity. Take the example of Wal-Mart, which has not only pledged to reduce its own energy consumption by 30 percent over seven years, but has also begun actively to promote the use of energy-saving CFL to its millions of customers. In general, private-sector players can help overcome agency problems that are present at the microlevel by seeking ways to create economies of scale for energy-efficient products. For example, one could imagine a group of small-appliance manufacturers, marketers, or retailers forming a consortium to reduce global standby-power requirements.

**Continued investment in improving residential energy efficiency** through the development of higher-efficiency equipment would be another priority—and may even be considered to be a strategic economic investment. As deep societal concerns about a scarcity of energy and about environmental degradation, including $CO_2$ emissions, increase, it is perfectly possible for a country that takes the lead in designing and manufacturing energy-efficient equipment to create an invaluable economic advantage for itself, including opening up export markets all the more potentially valuable because economies of scale often mean that more efficient equipment costs no more to manufacture than less efficient equipment.

Finally, removing residential energy subsidies **could help capture as much as 10 to 20 percent of the residential energy productivity opportunity**. Removing price subsidies on residential natural gas, petroleum products, and electricity, prevalent in developing economies, can have a large impact at country-level. However, this action's overall impact on uncertainty is not as significant as other factors. In our country-case studies, removing subsidies would result in a 3 QBTU reduction in global energy demand—with 2 of the 3 QBTUs coming from removing the heating subsidy in Russia (Exhibit 39). Although we did not analyze the Middle East in detail, we know that large subsidies are also present there and a rough estimate shows that removing residential subsidies in this region would yield another 3 QBTUs of savings. All told, we estimate that removing subsidies in the residential sector would reduce global residential energy demand by up to 5 percent, with the bulk of the improvement coming from developing countries.

**Exhibit 39**

REMOVING SUBSIDIES COULD REDUCE ENERGY DEMAND, ESPECIALLY RUSSIA'S SUBSIDY ON HEAT



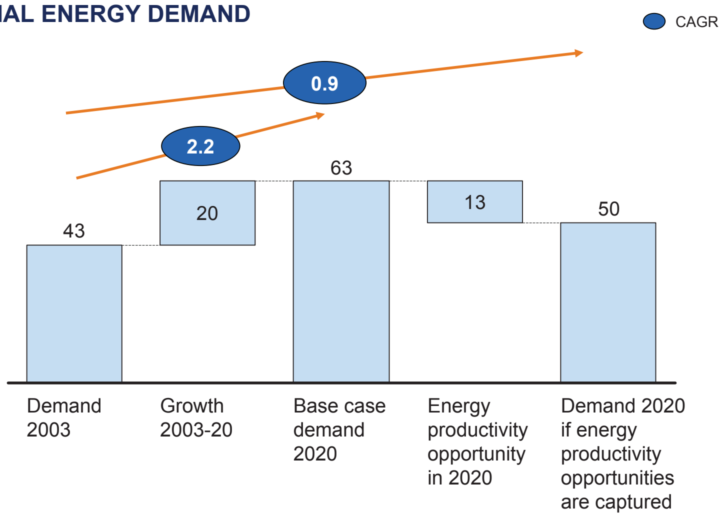

Source: MGI Global Energy Demand Model

This is not a trivial challenge, given that these subsidies are often intended to alleviate poverty and ensure that all sections of society have access to vital services such as heat. It remains the case, however, that subsidies often encourage overconsumption of energy. More targeted measures such as transfer payments would not only reduce energy waste but also potentially involve less of a drag on government budgets. Obviously, removing energy subsidies is always a politically charged issue, so it is well worth devising solutions that take such sensitivities into account and therefore minimize any adverse reaction.

## Most global commercial energy demand still comes from developed economies

- Commercial is the end-use sector with the highest proportion of demand still coming from developed economies—a 60 percent share.
- In the period to 2020, 75 percent of annual 2.2 percent commercial energy demand growth MGI projects will come from developing countries, with 48 percent from China alone.
- Floor space will grow by 4.8 percent in China and 4.6 percent in India annually to 2020—but by only 1.7 percent in the United States.
- The sector's sensitivity to changes in the oil price is low—end-user energy demand growth would decrease by only 0.1 percent a year between the $30-oil and $70-oil scenarios.
- The commercial sector could cut its 2020 demand for energy by 20 percent compared with MGI's base case if available energy productivity opportunities were to be captured.

**COMMERCIAL ENERGY DEMAND**
QBTU




| | | | | | |
|---|---|---|---|---|---|
| **Global total** % | 10 | 10 | 10 | 10 | 10 |

Source: MGI Global Energy Demand Model

# Commercial sector

## I. EXECUTIVE SUMMARY

Global energy demand from the commercial sector—including office and retail buildings, hotels and restaurants, and buildings used for schools and hospitals will grow by 2.2 percent a year to 2020, in line with global energy demand. The sector will, therefore, maintain its current share of total energy demand of some 10 percent. Developing regions' demand will grow strongly, due to robust GDP growth and to a broad expansion of these economies' service sectors. In developed regions, demand will continue to grow moderately, with several governments pushing forward energy-efficiency initiatives, a key driver of energy productivity in this sector.

In the period to 2020, 75 percent of commercial sector energy demand growth will come from developing countries. China stands out, with annual growth of 7.1 percent, well above, for instance, the United States with 1.0 percent. As a result, China will contribute 48 percent of the sector's growth during this period. The sector's shift toward power and natural gas will accelerate.

Our base-case growth forecast is subject to two significant uncertainties—GDP growth to which floor-space growth is strongly correlated, and the pace of energy-efficiency improvements. Our base case predicts that commercial floor space will grow at some 3 percent per annum to 2020 in all developing regions, with significantly stronger growth in China and India. Our expectations for demand abatement from energy-efficiency improvements are modest—ranging between 0.3 percent and 0.6 percent a year for all regions except China—as the sector continues to face market imperfections related to lack of information and agency issues, which are also found in the residential sector.

However, we estimate that the sector's 2020 projected demand for energy could be cut by 20 percent if available energy productivity opportunities were to be captured—equal to lowering final demand by 13 QBTUs—7 QBTUs of final demand and an additional 6 QBTUs of related power losses. Measures to capture this energy productivity could span a wide range: information and advice programs, aggressive demand-side-management programs run by utilities, increased efficiency in public-sector buildings, or the introduction or tightening of building codes and minimum efficiency standards for key appliances and HVAC equipment.

## II. COMMERCIAL SECTOR ENERGY DEMAND SIZE, GROWTH, AND FUEL MIX

### Size and regional breakdown of energy demand, 2003

As defined by the Energy Information Agency (EIA), commercial refers to any building that is used for neither residential, manufacturing, nor agricultural purposes.[1] The main types of commercial buildings include office buildings, hotels, restaurants, and warehouses, as well as buildings used in retail, health care, and education. This sector therefore embraces a diverse range of activities that can be performed by private or public entities.

In 2003, end-use energy demand in the commercial sector, including the allocation of power losses, stood at 43 QBTUs, representing 10 percent of global energy demand (Exhibit 1). Of this, 60 percent came from developed regions, reflecting the fact that commercial sector energy demand tends to take off at later stage of development, as the service sector share in economic activities increases. The United States alone contributed 34 percent of global demand, Europe[2] 23 percent, and Japan 8 percent. China, with 10 percent of global demand, accounted for one-quarter of developing regions' demand (Exhibit 2).

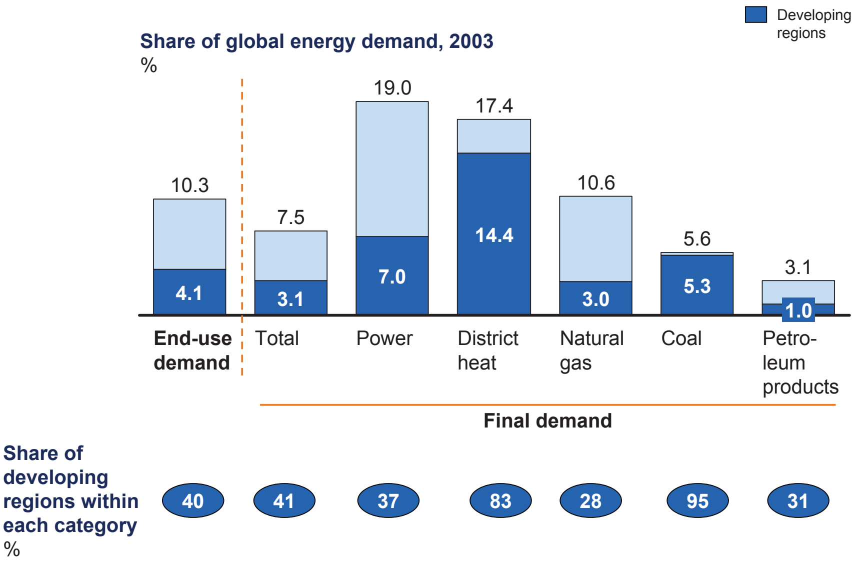
Commercial sector energy intensity varies widely between economies. For every dollar of services GDP, energy consumed can be as high as 10,100 BTUs in China or as low as 1,000 BTUs in Japan. Key developing regions are all on the high side—the Middle East with 8,700, Russia with 8,200, and Korea with 4,400. The United States and Northwestern Europe both consume less than 2,000 BTUs per dollar of services GDP (Exhibit 3).

1 *Commercial Buildings Energy Conservation Survey* (CBECS), EIA, (www.eia.doe/gov/emeu/cbecs/faq.html).

2 Europe includes the following regions: Northwestern Europe (14 percent of global demand), Mediterranean and North Africa (6 percent), and Baltic and Eastern Europe (3 percent). Northwestern Europe is classified as a developed region, while the other two regions are classified as developing.

## Exhibit 1

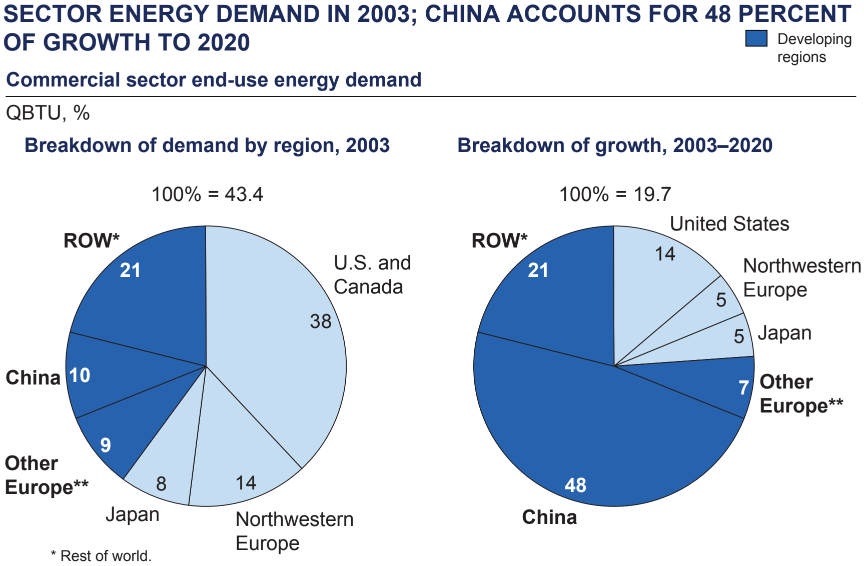
### THE COMMERCIAL SECTOR REPRESENTS 10 PERCENT OF GLOBAL END-USE DEMAND AND 19 PERCENT OF GLOBAL POWER DEMAND




Source: IEA; MGI analysis

## Exhibit 2

### DEVELOPED REGIONS REPRESENT 60 PERCENT OF COMMERCIAL SECTOR ENERGY DEMAND IN 2003; CHINA ACCOUNTS FOR 48 PERCENT OF GROWTH TO 2020



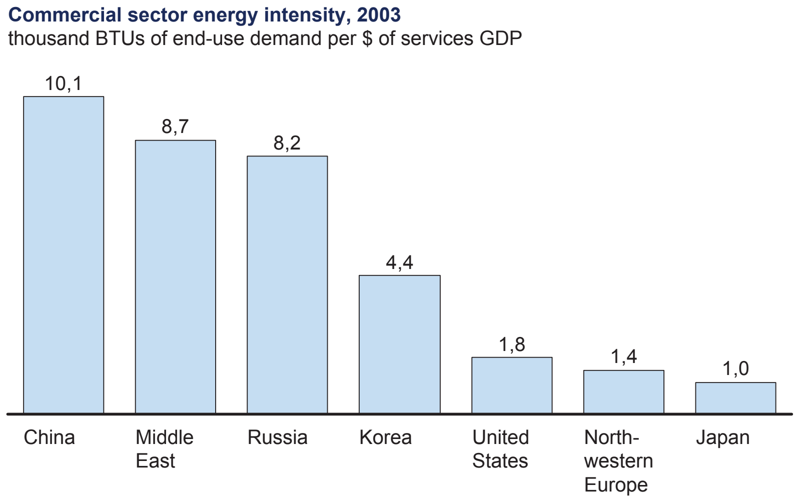

* Rest of world.

** Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.

Source: MGI Global Energy Demand Model

**Exhibit 3**

ENERGY INTENSITY VARIES SIGNIFICANTLY BY REGION



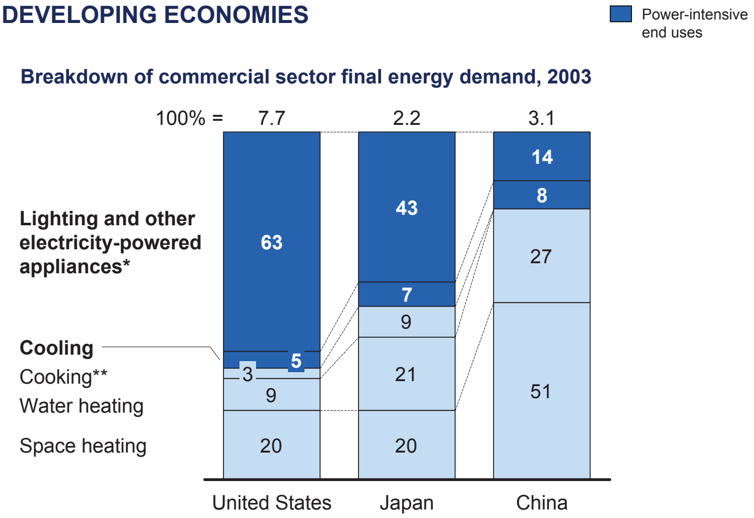

Source: Global Insight; MGI analysis

In terms of fuel mix,[3] the commercial sector's share of global demand in 2003 varied from 19 percent for power and 17 percent for district heat to a mere 3 percent for petroleum products. The relative weight in terms of fuel demand also varied between developed and developing regions—for instance, developing regions contributed 83 percent of the sector's overall demand for heat, yet only 28 percent of its demand for natural gas. Two factors explain this. First, the sector's mix of different end uses varies across regions—the share of space and water heating, two of the "basic" energy services in buildings, is approximately one-third in developed regions, while it can reach 75 percent or more in developing regions such as China (Exhibit 4). Second, there are sharp differences in the fuel mix for key end uses: space-heating fuel is 78 percent natural gas in the United States; in Japan, it is 79 percent distillate; in China, it comprises 48 percent coal and 25 percent district heat (Exhibit 5). Natural gas is a clean, convenient fuel for space heating, widely adopted by consumers in developed regions depending on its availability. In that respect, fuel mix in Japan remains constrained by limited domestic-energy supply and the need to import high-density fuels (distillate). In China, the fuel mix reflects a historical reliance on centralized district heating as well as the country's greater availability of coal.

3 References to fuel mix throughout this paper are based on final energy demand numbers, since end-user demand figures include both final demand and losses from the transformation sector.

## Exhibit 4

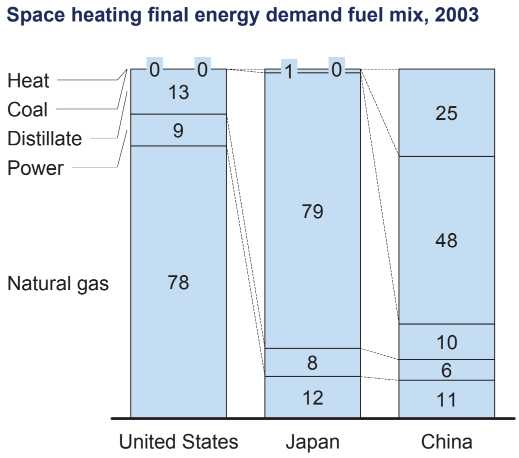
### THE END-USE MIX IN DEVELOPED REGIONS IS MORE POWER-INTENSIVE THAN IN DEVELOPING ECONOMIES




* Other uses include refrigeration, ventilation, office equipment, and other appliances.
** Data on cooking not available for China.
Source: EIA; 2005 Handbook of Energy & Economic Statistics in Japan; LBNL; MGI analysis

## Exhibit 5

### SPACE-HEATING FUEL MIX VARIES ACROSS REGIONS DEPENDING ON CONSUMER PREFERENCES AND SUPPLY CONSTRAINTS



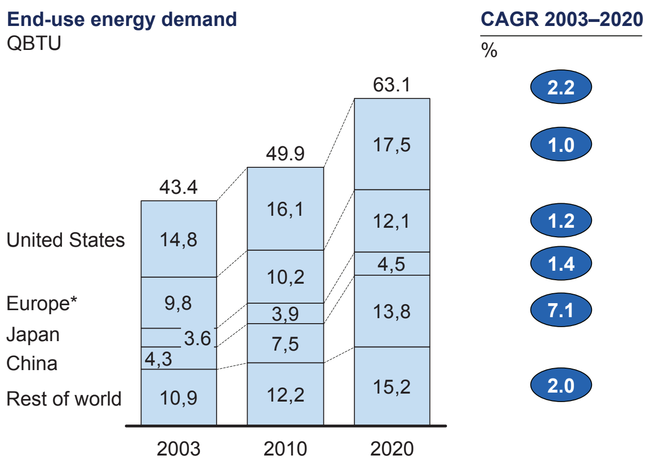

Source: EIA; 2005 Handbook of Energy & Economic Statistics in Japan; LBNL; MGI analysis

### Growth of energy demand and $CO_2$ emissions

Going forward, our base-case scenario[4] shows end-use energy demand growing at 2.2 percent annually to 2020—a 19.7 QBTU increase from 43.4 to 63.1 QBTUs. The commercial sector's share of overall global energy demand will remain around 10 percent. China stands out with annual growth of 7.1 percent (leading to a tripling of its demand by 2020), well above other developing regions (2.0 percent) and major developed regions (1.0 percent in the United States and 1.2 percent in Europe) (Exhibit 6). As a result, China will contribute 48 percent of the sector's growth to 2020.

**Exhibit 6**

**COMMERCIAL SECTOR END-USE ENERGY DEMAND WILL GROW AT 2.3 PERCENT A YEAR TO 2020 – A 19.7 QBTU INCREASE**




* Including Northwest Europe, Mediterranean and North Africa, and Baltic/Eastern Europe.
Source: IEA; MGI Global Energy Demand Model

Overall, developing regions will generate 75 percent of growth in commercial sector energy demand to 2020, as their emerging middle classes spend a growing share of their income on services and aspire to the levels of comfort and convenience enjoyed by consumers in developed regions. Developing regions' share of the sector's global demand will increase from 40 percent to 51 percent by 2020 (Exhibit 7).

Compared with the historical trend[5] observed in 1994–2003, energy demand growth remains stable in the commercial sector globally.

4 $50-oil and base-case GDP scenario.

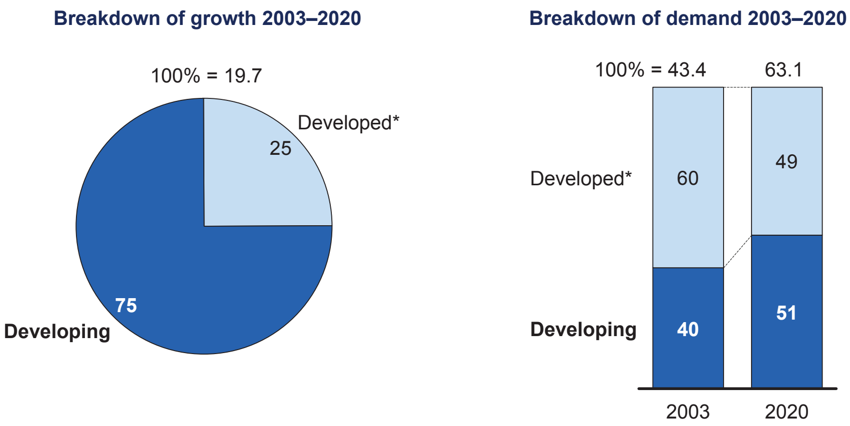
5 Due to data limitations, the comparison with historical growth trends is established for final energy demand.

## Exhibit 7

### COMMERCIAL SECTOR ENERGY DEMAND GROWTH WILL BE DRIVEN BY DEVELOPING REGIONS

**Commercial sector end-use energy demand**

QBTU, %




* United States, Canada, Japan, and Northwestern Europe.
Source: MGI Global Energy Demand Model

This is the result of the balance between lower growth in developed regions and slightly higher growth in developing economies, which will see a growing share of global demand[6] (Exhibit 8).

Overall, the sector's $CO_2$ emissions will grow from 2,460 million metric tons in 2003 to 3,770 tons in 2020, a 2.5 percent growth rate.

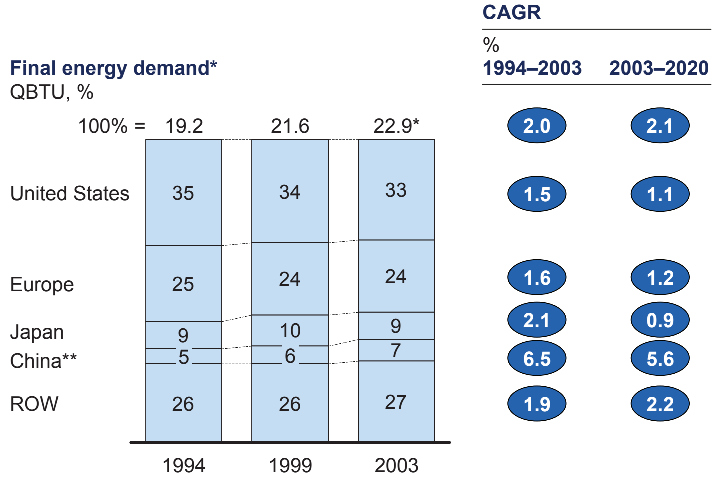
### Sector fuel mix

In terms of fuel mix, we expect a continuation of the historical trend toward increased shares of power and natural gas in sector's overall demand. Final demand for power and natural gas will grow faster than the demand for the sector as a whole, at 2.9 percent and 2.7 percent respectively; their combined share of the sector's demand will grow from 69 percent to 77 percent (Exhibit 9). Matching this will be a corresponding decrease in the shares of petroleum products (distillate), for which demand will remain flat, and of coal, for which demand will decrease by more than 2 percent a year, largely as the result of a radical fuel-mix change in China.

6 Although projected growth in China appears to be slightly lower than historic growth, China's higher share of global demand contributes to increasing weighted global growth, especially since the Lawrence Berkeley National Lab (LBNL) 2003 data adjustment for China increases its share of the sector's demand from the International Energy Agency's (IEA) 7 percent to 13 percent.

## Exhibit 8

### MGI PROJECTION IS IN LINE WITH THE HISTORICAL GROWTH TREND AT WORLD LEVEL, WITH A DECELERATION IN DEVELOPED REGIONS



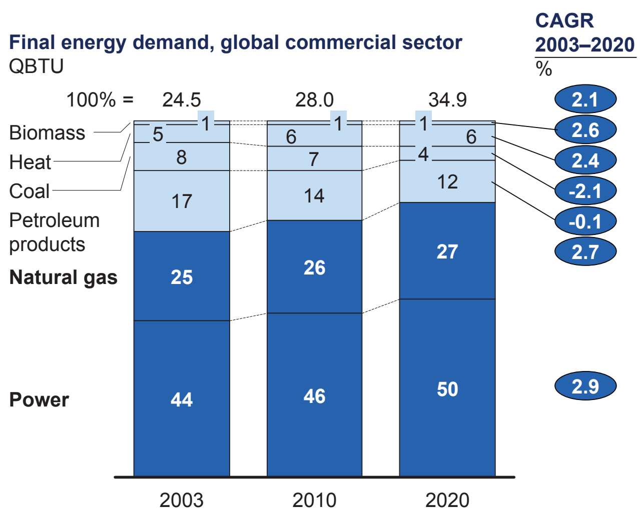

* Due to data limitations, the comparison to historical growth trends is established for final energy demand.

** The IEA 2003 total differs from the MGI baseline due to adjustments to China's commercial sector demand to reflect the LBNL reclassification of energy demand by sector.

Source: IEA; MGI Global Energy Demand Model

## Exhibit 9

### THE COMMERCIAL SECTOR FUEL MIX WILL BE INCREASINGLY DOMINATED BY POWER AND NATURAL GAS

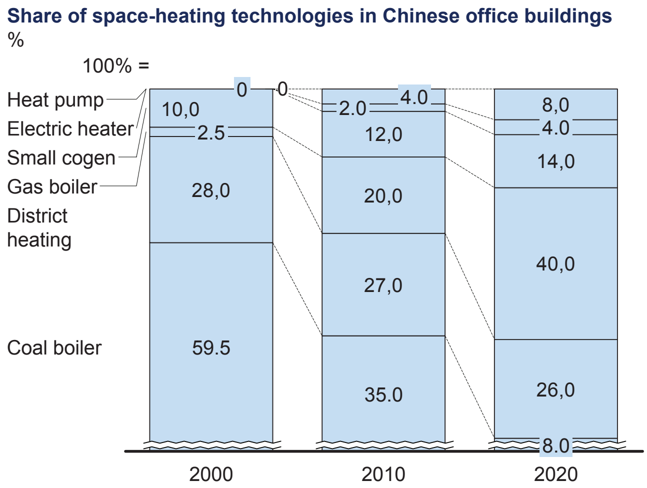



Source: MGI Global Energy Demand Model

Indeed, the most spectacular fuel-mix change will be in China, which will see a shift in the mix of demand for energy services and of the technology choices to meet this demand. Space heating provides us with an illustration—its share of commercial sector demand will decline from half in 2005 to one-third in 2020, while the share of power-intensive end uses such as air-conditioning, lighting, and office equipment will double to 50 percent. Simultaneously, the mix of space-heating technologies will shift away from coal boilers to more efficient technologies such as natural-gas boilers and electricity-powered heat pumps (Exhibit 10). As a result, the share of coal in China will drop from 49 percent to 12 percent between 2003 and 2020, while the share of power and natural gas will more than double and triple to 47 percent and 19 percent respectively, bringing China closer to the global average (Exhibit 11).

**Exhibit 10**

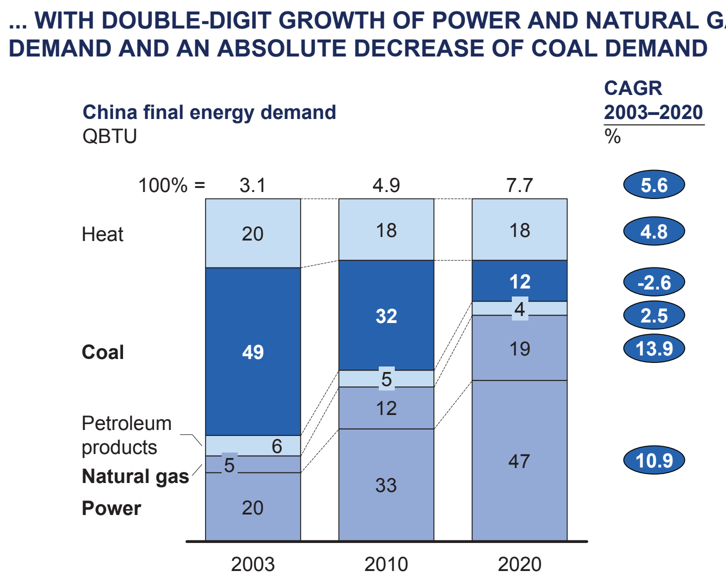
**A RADICAL SHIFT IN CHINA'S SPACE-HEATING TECHNOLOGY CHOICES WILL LEAD TO A DRAMATIC CHANGE IN FUEL MIX ...**




Source: LBNL, China Energy Group

A number of other developing regions will also see significant change in their fuel mix, but the impact of this on the global fuel mix will be limited because they account for a relatively small share of global demand. India, for example, will continue its historical trend away from the direct burning of coal and toward electricity. Coal represented 75 percent of demand in 1994 and 55 percent in 2003, and its share will fall to 20 percent by 2020.

**Exhibit 11**




Source: LBNL, China Energy Group; MGI analysis

In developed regions, the historical shift away from petroleum products (distillate) will continue. As a result, the share of natural gas in Northwestern Europe[7] will increase from 25 percent to 40 percent. In Japan, the share of petroleum products will fall from 50 percent to 35 percent, with power and natural gas each capturing half of the difference. Projections of expanded availability of liquefied natural gas (LNG) partly explain this shift toward natural gas in Japan. In the United States, however, the fuel mix will remain stable, since power and natural gas already make up 90 percent of final demand in 2003 (Exhibit 12).

## III. DRIVERS OF ENERGY DEMAND

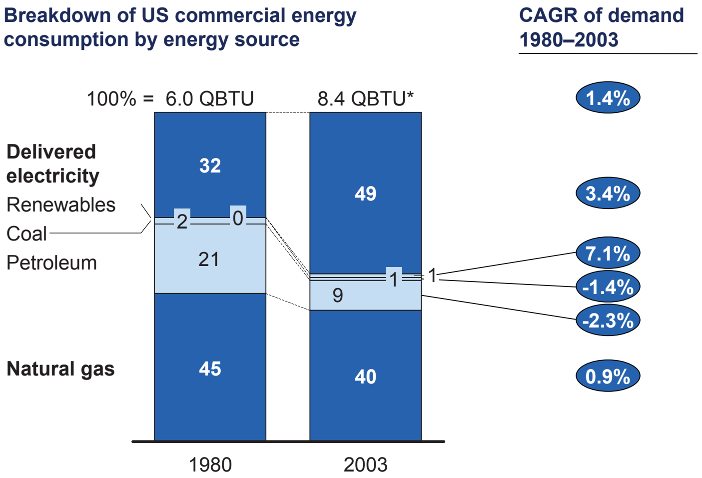
### Case-study methodology and sources

Commercial sector energy demand growth can be broken down into two microeconomic drivers—commercial floor-space growth and net energy-efficiency improvements (Exhibit 13). Floor-space expansion is proportional to the growth in services GDP, with a specific "multiplier" by region. Net energy-efficiency improvements arise out of the sector's efficiency potential and of the rate at which it is expected to capture this potential, itself largely driven by energy-efficiency policies. The term net refers to "net of changes in end-use intensity and penetration." This distinction is most relevant for developing regions where end-use penetration and intensity are increasing.

7 Northwestern Europe includes Belgium, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Switzerland, and the United Kingdom.

## Exhibit 12

### POWER AND NATURAL GAS ALREADY MAKE UP 90 PERCENT OF US COMMERCIAL SECTOR ENERGY DEMAND

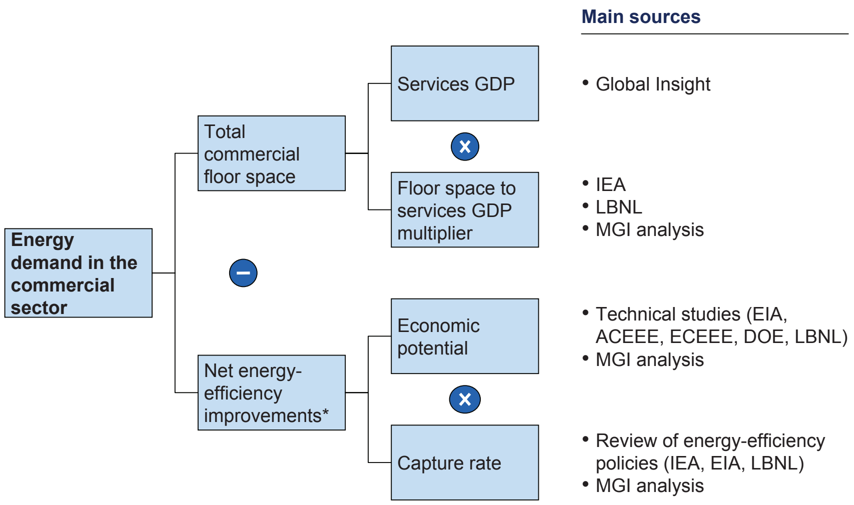



* The EIA 2003 total differs from the MGI baseline due to differences in statistical classification.

Source: EIA Annual Energy Review, 2004; MGI analysis

## Exhibit 13

### COMMERCIAL SECTOR ENERGY DEMAND GROWTH IS DRIVEN BY FLOOR-SPACE GROWTH AND NET EFFICIENCY IMPROVEMENTS




* Improvement net of increased penetration of end uses.

Source: MGI analysis

In terms of geographic scope, our commercial case study focuses on the United States and China, the former for its current size, the latter for its projected contribution to future growth. We also cover other developed countries using a lighter version of the detailed bottom-up methodology. Together, these regions account for 75 percent of current commercial sector energy demand and close to 80 percent of its growth to 2020. We extrapolate key drivers for other developing regions from the historical growth path of China's commercial sector.

In terms of sources, we build on a wide range of publicly available data and studies, as well as on interviews with McKinsey experts and disguised client interviews. We source our projections of services value added by country from Global Insight, and data collected by the International Energy Agency (IEA) underlies our multipliers of floor space to services GDP. We also refer to several studies by the IEA, the EIA, the American and European Councils for an Energy-Efficient Economy (ACEEE and ECEEE) and the Lawrence Berkeley National Lab (LBNL), both to assess the energy efficiency potential and to review current and future energy-efficiency policies. For the Chinese commercial sector, the MGI has closely collaborated with LBNL's China Energy Group, which has built in-depth expertise on energy demand in China at the sector level and developed its own China buildings model.

**Floor-space growth**

We expect commercial floor space to grow approximately 3 percent per annum to 2020 in all developing regions,[8] except for China and India, which we see posting growth of 4.8 percent and 4.6 percent respectively. In contrast, the highest growth rate in developed regions will be 1.7 percent a year in the United States. Across all regions, growth will be faster to 2010 and will then decelerate to 2020 (Exhibit 14).

**Strong growth in demand for services in India and China**

Faster projected growth in developing regions importantly reflects their higher expected annual services-GDP growth to 2020: 6.1 percent in India, 6.7 percent in China,[9] and approximately 4 percent in all other developing regions. Services growth in developed regions will not match that in the developing world, the highest growth expected to be in the United States at 3.3 percent. We expect Japan to see only about half that rate at 1.8 percent (Exhibit 15).

8 Although classified as a developing region, Mediterranean and North Africa comprises a mix of developed (Italy, Spain) and developing countries, which explains the fact that its growth rate (2.4 percent) stands between that of developed and developing regions.

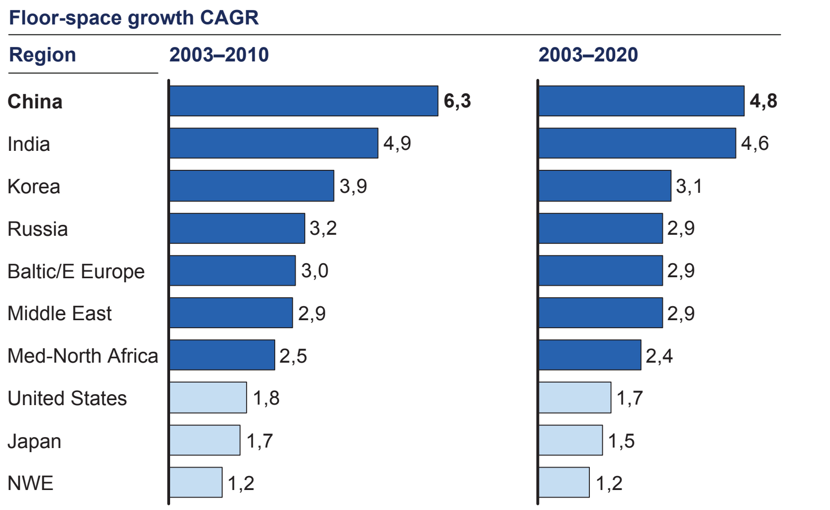
9 Due to data limitations, nominal GDP was used as a proxy for services GDP for China in this analysis.

## Exhibit 14

### FLOOR SPACE WILL GROW FASTEST IN DEVELOPING REGIONS, ESPECIALLY CHINA, WITH A DECELERATION AFTER 2010

%

Developing regions

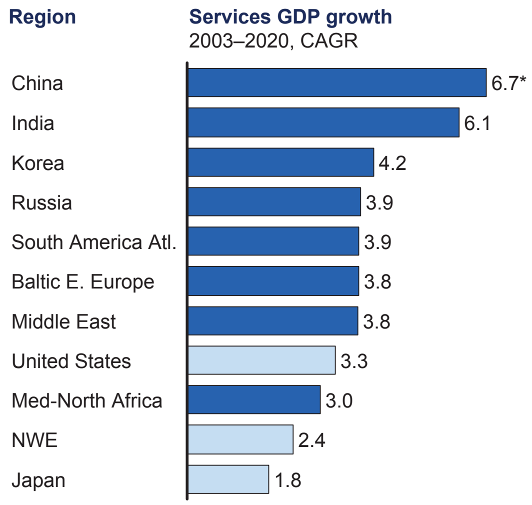



Source: MGI analysis

## Exhibit 15

### FASTER FLOOR-SPACE GROWTH IN DEVELOPING REGIONS IS TIED TO FASTER SERVICES-GDP GROWTH

Developing regions



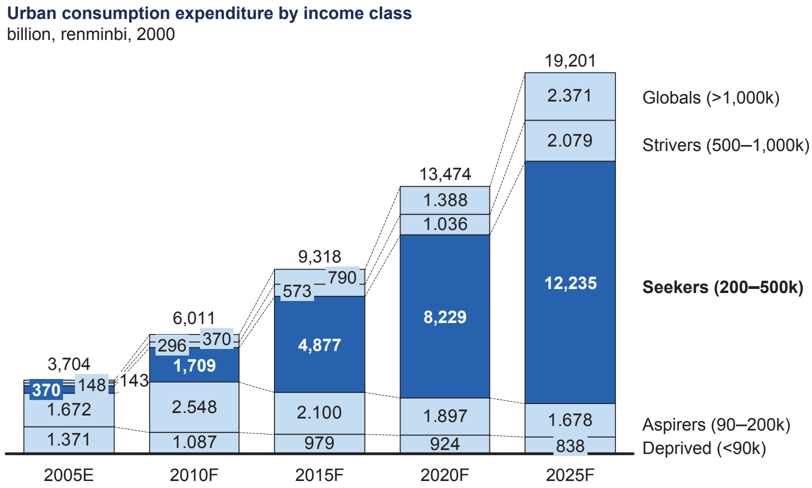

* Due to data limitations, real GDP was used as a proxy for services GDP for China in this analysis.

Source: Insight; MGI analysis

The high growth rate in China corresponds to the rise of the country's middle class, a phenomenon into which MGI is currently conducting extensive research. A recently released MGI report[10] shows that, by 2025, China will become the world's third-largest consumer market, approaching Japan in real-dollar terms. The study took a detailed approach by income class, and forecast, for example, that by 2025 there will be eight million "global" households in China with average spending of more than 290,000 renminbi per year, and 19 million affluent households with incomes between 100,000 to 200,000 renminbi per year and average spending of about 109,000 renminbi per year (Exhibit 16). The study also shows that the pattern of spending will change dramatically, with the share of discretionary spending, which includes services, increasing from 55 percent to 74 percent of total urban spending by 2025 (Exhibit 17).

**Exhibit 16**

**THE RISE OF CHINA'S URBAN MIDDLE CLASS WILL DRIVE STRONG GROWTH IN PRIVATE CONSUMPTION...**




Source: MGI China Consumer Demand Model

## Regional differences in the link between services GDP and floor space

Faster growth in developing regions can also be explained by the fact that the multiplier between their services GDP and floor-space growth is higher than for the largest developed regions—i.e., the United States and Northwestern Europe (Exhibit 18). We based these multipliers on historical data at country level; for developed regions, we used IEA data (Exhibit 19).[11] A first observation is that the

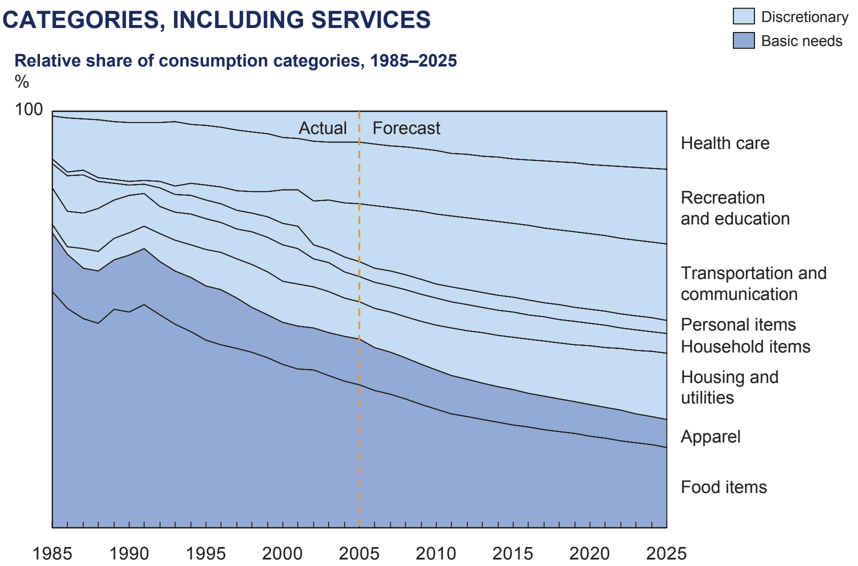
10 *From 'Made in China' to 'Sold in China': The Rise of the Chinese Urban Consumer*, McKinsey Global Institute, November 2006, (www.mckinsey.com/mgi)

11 *30 years of energy use in IEA countries,* IEA, 2004.

## Exhibit 17

### ... WITH A RAPID SHIFT OF SPENDING TOWARD DISCRETIONARY CATEGORIES, INCLUDING SERVICES

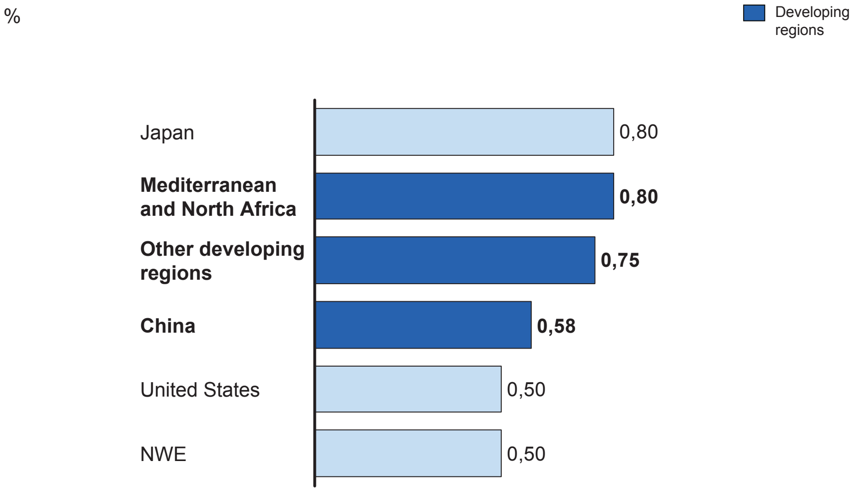
Relative share of consumption categories, 1985–2025




Source: MGI China Consumer Demand Model

## Exhibit 18

### DEVELOPING REGIONS HAVE A HIGHER MULTIPLIER OF FLOOR-SPACE TO SERVICES-GDP GROWTH THAN LARGEST DEVELOPED REGIONS

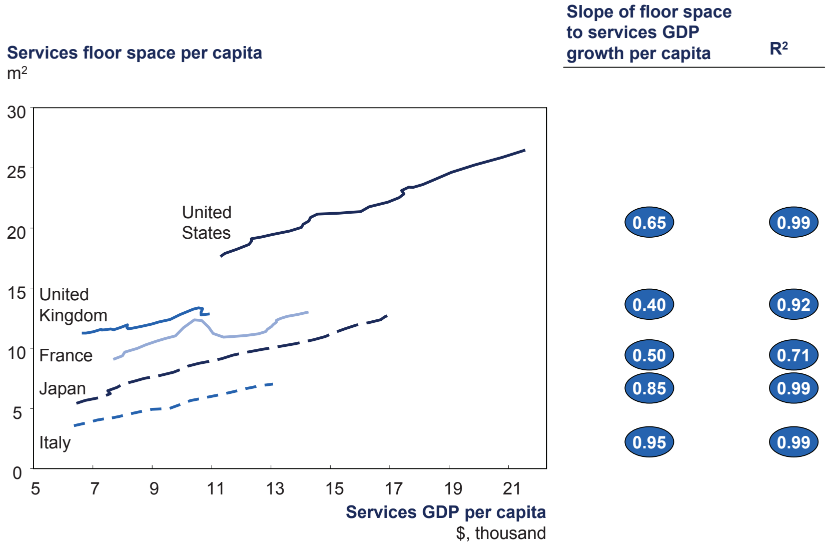



Source: IEA; MGI analysis

absolute levels of floor space per capita differ significantly among regions, with the United States having by far the highest reading. This ratio is linked to the physical availability of land (Japan being the most space-constrained), but also to regulation like zoning laws that may restrict land use. A second observation is that the link between services GDP per capita and floor-space growth is steady across time, and regression analyses by country therefore yield strong correlations. Using the slopes of these regressions, we estimated multipliers for each region—for example, using France and the United Kingdom for Northwestern Europe and Italy for the Mediterranean. For the United States, we adjusted the multiplier to 0.5 in order to reflect the EIA's assumptions, which are based on the best available data set for US commercial floor space.[12]

**Exhibit 19**

**HISTORICAL DATA SHOWS A LINK BETWEEN SERVICES GDP PER CAPITA AND FLOOR SPACE PER CAPITA FOR DEVELOPED REGIONS**




Source: *30 years of energy use in IEA countries*, IEA, 2004

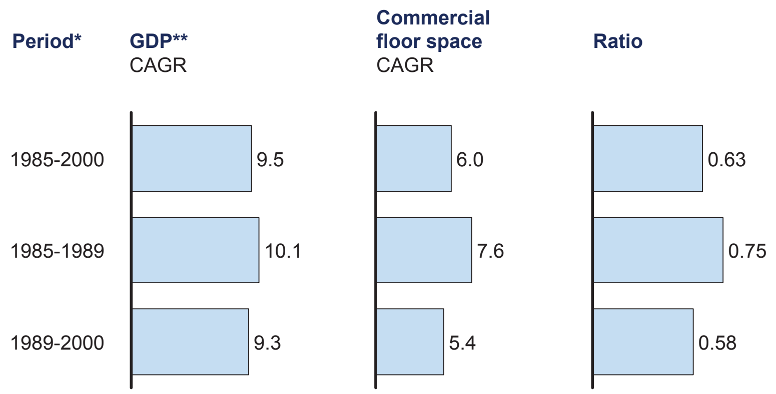
For China's commercial floor space, we used LBNL China Energy Group data for historical floor-space growth, and targets from the Chinese Ministry of Construction. We first compared GDP growth to commercial floor-space growth for years with available data. The ratio of floor space to GDP growth was 0.63 for the period 1985–2000, with a higher ratio of 0.75 in early years (1985–1989) and 0.58 for subsequent years (Exhibit 20). For our projections, we used the 0.75 ratio to 2010 to match official floor-space targets, and then the lower ratio for subsequent years. For other developing regions, we also used the lower ratio as

12 Data is drawn from F.W. Dodge Statistics and Forecasts Group.

an estimate to 2020, to reflect the fact that their commercial sectors are still in an early phase of development compared with that of China.[13]

**Exhibit 20**

**IN CHINA, THE RATIO BETWEEN FLOOR-SPACE GROWTH AND GDP GROWTH HAS DECLINED OVER TIME**




* Total commercial floor area could be derived only for 1998 and 2000 from existing research. The rest of the years were estimated based on China's statistical yearbook.
** Due to data limitations, GDP was used as a proxy for services GDP in this analysis.
Source: LBNL; Global Insight; MGI analysis

### Penetration and intensity of building-energy end uses

As consumers become wealthier, they demand higher levels of comfort and convenience, with direct implications for commercial buildings' energy consumption. As the services sector develops in an economy, penetration of building-energy end uses increases, first for "basic" end uses such as space heating, then for air-conditioning, as well as for other power-intensive appliances and equipment (such as computers in office buildings and advanced medical equipment in hospitals). The intensity of use also increases—retail stores, for example, replace neon lights with more customer-friendly lighting, or thermostats are set lower/higher depending on the climate.

In developed regions, we project penetration and intensity to remain stable for most end uses, with the exception of office equipment. This reflects the fact that these regions have either reached saturation points, especially for basic end uses such as space heating or lighting, or that the adoption of more advanced end uses is limited by non-income-related constraints. For instance, the penetra-

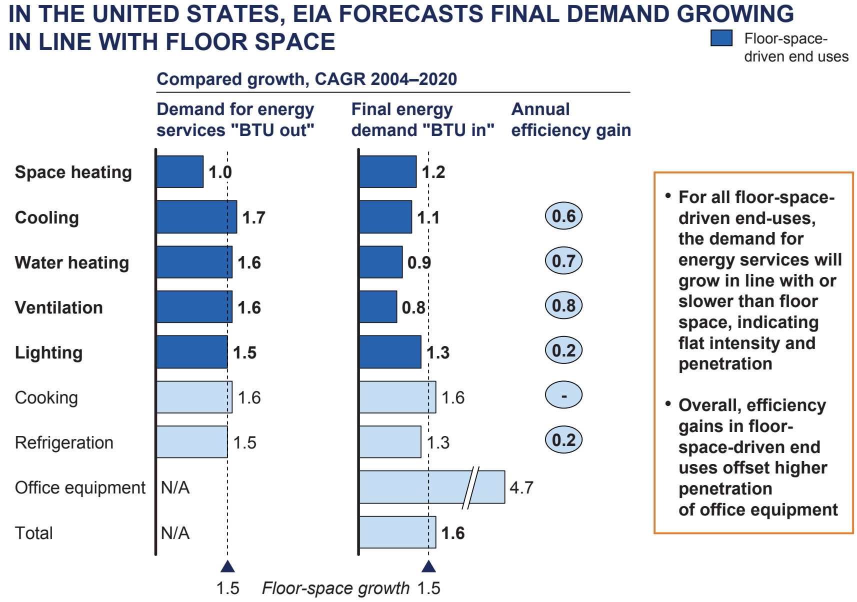
13 This methodological choice was driven partly because of lack of data for other developing regions, and also because China has by far the largest commercial sector among developing countries.

tion of air-conditioning is projected to remain low in a number of large European countries such as Germany despite high levels of income per capita.

In the United States, we tested this assumption against detailed EIA projections, which show end-use intensity and penetration of floor-space-driven energy services either declining (space heating) or remaining flat (cooling, water heating, ventilation, lighting), since their "BTU out"[14] demand grows at the same pace as floor space. Furthermore, all these end uses experience business-as-usual efficiency improvements (except space heating). For instance, water heating, for which "BTU in" demand grows at 0.9 percent and "BTU out" demand grows at 1.6 percent, indicates an annual efficiency gain of 0.7 percent. Together, these effects compensate for increased penetration of office equipment (4.7 percent growth), as evidenced by the fact that the sector's final energy demand grows in line with floor space (Exhibit 21).

**Exhibit 21**

**IN THE UNITED STATES, EIA FORECASTS FINAL DEMAND GROWING IN LINE WITH FLOOR SPACE**




Source: EIA AEO 2006; MGI analysis

By contrast, the intensity and penetration of several end uses will increase in developing regions, especially in China. The LBNL China Energy Group's Buildings model, which integrates projections by the Chinese Energy Research Institute,[15]

14 For example, the number of BTUs that a piece of heating equipment needs to deliver in order to heat a 1,000-cubic-foot room by 10 degrees for three months, regardless of the efficiency of this equipment and its resulting energy consumption ("BTU-in").

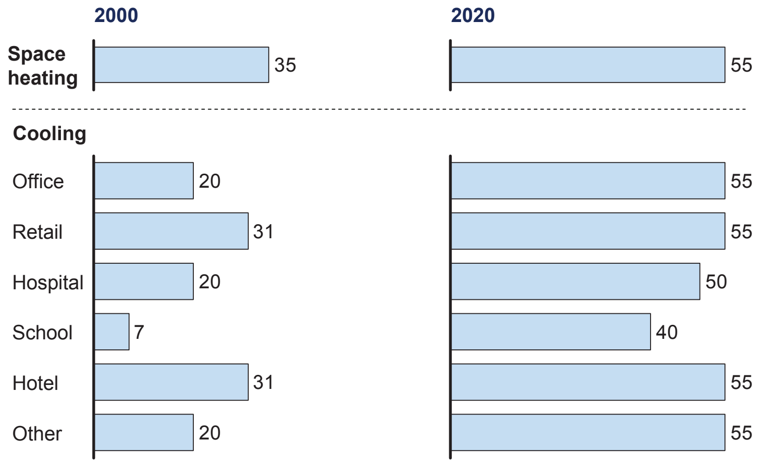
15 *China's Sustainable Energy Scenarios in 2020,* Energy Research Institute.

takes this trend directly into account. Penetration of space heating, by far the largest end use today in China, will increase from 35 percent in 2000 to 55 percent in 2020. Penetration of heating in southern regions, which has historically been low, will continue to expand as in recent years. Similarly, only a fraction of commercial buildings are currently air-conditioned, with very low penetration in older buildings and in hospitals and schools. LBNL expects the penetration rate to reach 55 percent for most building types by 2020 (Exhibit 22).

**Exhibit 22**

**IN CHINA, PENETRATION OF MAIN-BUILDING ENERGY END USES IS PROJECTED TO INCREASE SIGNIFICANTLY ACROSS ALL SECTORS...**

**End-use penetration in China commercial sector, 2000–2020**
%




Source: LBNL, China Energy Group; ERI

As a result, China is the only region in our base-case scenario where final energy demand outgrows floor space (5.6 percent versus 4.8 percent), since increased penetration will outweigh the efficiency improvements we detail in the following section (Exhibit 23). For other developing regions, as we will explain, we model this effect, which we expect to be more moderate, by adjusting downward the capture rate of the energy-efficiency potential.

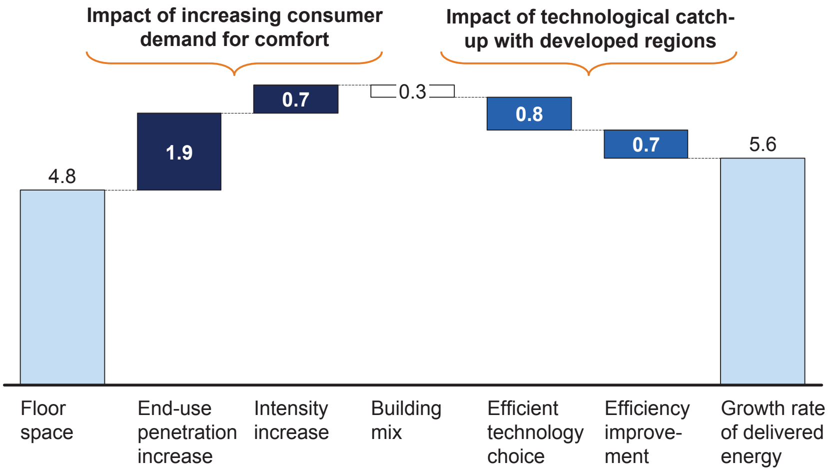
### Energy efficiency

For each region, we derive the impact of energy-efficiency improvements by combining an economic-efficiency potential and its projected capture rate. This calculation results in an annual energy demand reduction compared with "business-as-usual" of between 0.3 percent and 0.6 percent for all regions except in China (Exhibit 24). This narrow range across regions conceals a diversity of combinations. For instance, developing regions (excluding China) and Northwestern

## Exhibit 23

### ... AND WILL MORE THAN OFFSET PROJECTED ENERGY-EFFICIENCY IMPROVEMENTS

**Key drivers of China commercial sector energy demand growth, 2003–2020**
%

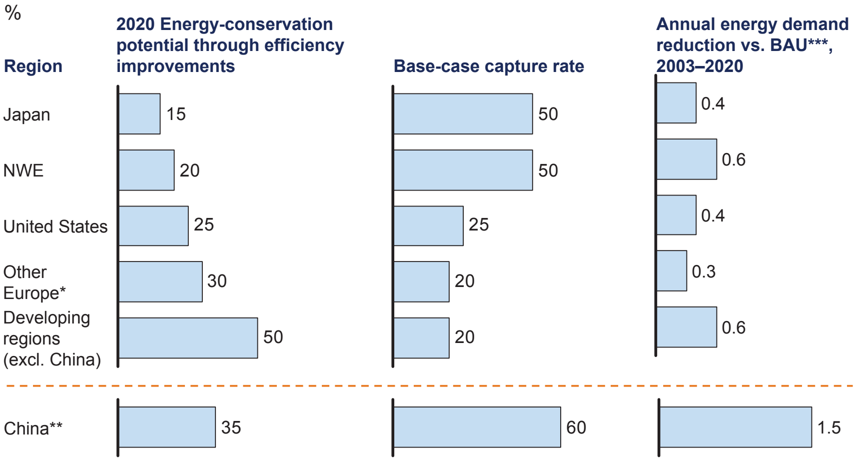



Source: LBNL, China Energy Group; MGI analysis

## Exhibit 24

### COMBINED ECONOMIC POTENTIAL AND CAPTURE RATE NETS ANNUAL EFFICIENCY GAINS OF 0.3–0.6 PERCENT

%




* Mediterranean and North Africa and Baltic/Eastern Europe.
** For China, the MGI model directly integrates results and assumptions from LBNL's China Buildings model.
*** Business-as-usual.

Source: Energy-efficiency potential studies and policy-outlook analysis by country: IEA, EIA, LBNL, ACEEE; ECEEE; EU and EU member-state government websites; MGI analysis

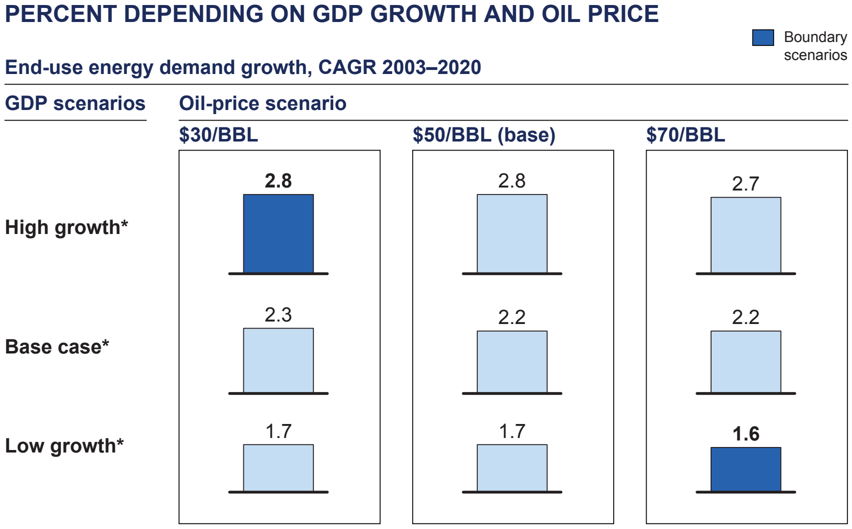
Europe achieve the same gains, the former by capturing 20 percent of a 50 percent improvement potential, and the latter capturing 50 percent of its 20 percent potential. Japan captures a similarly large share of its 15 percent potential, resulting in annual demand reduction of 0.4 percent. The United States achieves the same reduction as Japan with a 25 percent potential and a 25 percent capture rate.

## IV. KEY UNCERTAINTIES AROUND THE MGI BASE-CASE SCENARIO

Several variables create uncertainty around our base-case scenario for energy demand growth in the global commercial sector, including GDP-driven floor-space growth and energy prices. Only GDP creates significant uncertainty. When we combine them (e.g., high GDP growth and low oil price, or vice versa), they could drive demand growth as high as 2.8 percent a year or as low as 1.6 percent annually, a possible swing in 2020 demand of 13 QBTUs (Exhibit 25).

**Exhibit 25**

**ENERGY DEMAND GROWTH COULD SWING BETWEEN 1.6 AND 2.8 PERCENT DEPENDING ON GDP GROWTH AND OIL PRICE**

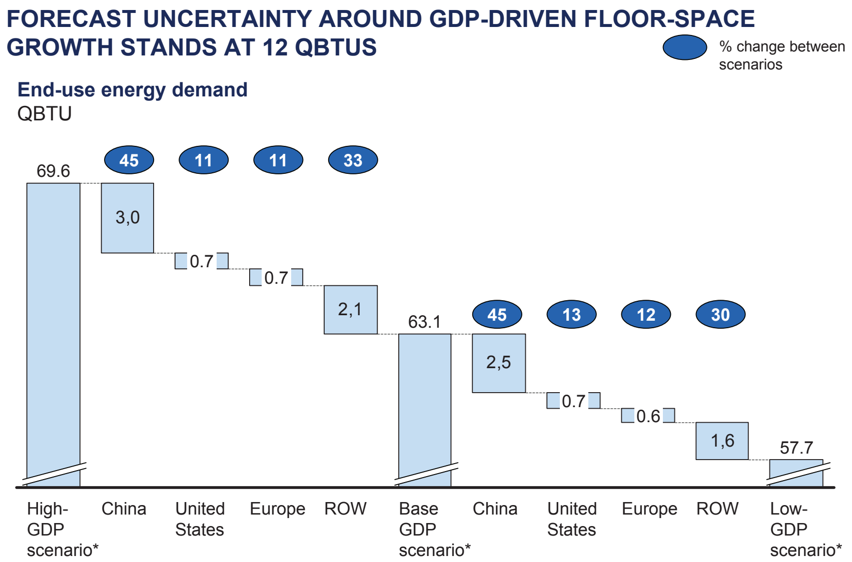



* Base-case growth of 3.2% globally; variations of ±2% for China and India, ±1% for other developing regions, and ±0.5% for developed economies.
Source: MGI Global Energy Demand Model

### GDP growth

Our GDP scenarios assume variations versus our base case of plus or minus 2 percent for China and India where GDP projections carry the most uncertainty, plus or minus 1 percent for other developing regions, and plus or minus 0.5 percent for developed economies. Using this methodology, 45 percent of the difference between scenarios would come from China, and less than 25 percent from the United States and Europe combined (Exhibit 26). Our various GDP-growth scenarios show annual demand growth could be as low as 1.7 percent (a 5 QBTU reduction) or as high as 2.8 percent (a 7 QBTU increase).

**Exhibit 26**




* Base-case growth of 3.2% globally; variations of ±2% for China and India, ±1% for other developing regions, ±1%, and ±0.5% for developed economies.

Source: MGI analysis based on MGI Global Energy Demand Model

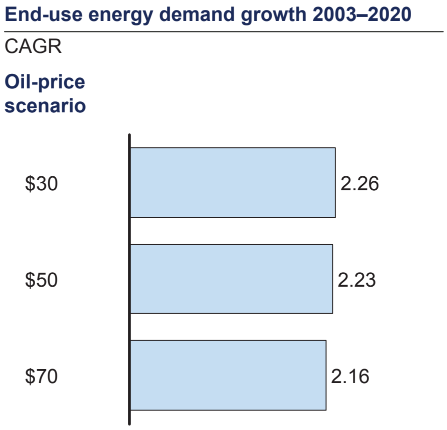
## Energy prices

We do not expect a strong direct impact of energy prices on commercial energy demand. The sector's end-user energy demand growth would decrease by 0.1 percent annually between the $30-oil and $70-oil scenarios—a total demand reduction of less than 1 QBTU (Exhibit 27).

There are a number of reasons why the commercial sector's direct elasticity to oil price is low. First, the retail price of electricity, an important fuel in the commercial sector, correlates only weakly to the oil price. Second, the share of energy costs for most commercial consumers has historically been modest and steadily decreasing since the 1970s. This explains why behavioral response to higher prices in the sector is moderate, as evidenced by several academic studies that show short-term price elasticity of around minus 0.2. Interestingly, many of these studies also show significant long-term price elasticity in the sector, but none of them control for regulatory factors (Exhibit 28). It is standards, often introduced or tightened in response to higher energy prices, which drive energy-efficiency improvements. We can therefore best describe the impact of price on demand as an indirect elasticity occurring through the regulatory channel.

## Exhibit 27

### THE COMMERCIAL SECTOR SHOWS LITTLE DIRECT RESPONSE TO HIGHER OIL PRICE




Source: MGI analysis based on MGI Global Energy Demand Model

## Exhibit 28

### ACADEMIC STUDIES SHOW LOW SHORT-TERM PRICE ELASTICITY IN THE COMMERCIAL SECTOR, BUT ESTIMATES OF LONG-TERM ELASTICITY MAY REFLECT TIGHTER REGULATION

| Study<br>Year | Years covered | Short-term elasticity | Long-term elasticity |
|---|---|---|---|
| Taylor (1975) | Review of existing studies | -0.17 | -1.36 |
| Rand for DOE (2005) | 1979–99 | -0.21 | -0.97 |
| *Land economics** (2003) | 1986–92 | | -0.70 |
| EIA (2003) | 1979–99 | | |
| • Electricity** | | -0.20 | -0.45 |
| • Natural gas** | | -0.29 | -0.40 |

* Long-term elasticity of electricity demand for buildings using electricity only.
** Long-term elasticity for all buildings.
Source: Literature review

## V. ENERGY PRODUCTIVITY OPPORTUNITY

Only a small share of the commercial sector's energy productivity potential is currently being captured. In this section, we look first at the size of the potential itself, identifying opportunities for energy efficiency improvements that rely on currently existing technologies and have an internal rate of return (IRR) of 10 percent or more. We then examine why such a significant amount of the potential for higher energy productivity is not being tapped.

Overall, assuming that all regions capture their full energy productivity potential would lead to additional 20 percent demand abatement versus our base-case scenario. This would lower 2020 commercial sector end-use energy demand by 13 QBTUs—7 QBTUs of final demand and an additional 6 QBTUs of related power losses. In order to capture this full potential, current energy-efficiency policies would have to be not only fully implemented but also significantly strengthened.

**Energy productivity opportunity by region**

Our energy productivity opportunity assessment builds on existing available studies by region. For the United States, the region with the largest number of relevant studies, many of them at state level, the analysis converges on an energy productivity opportunity between 20 percent and 30 percent. We used a 2004 metastudy by the ACEEE that reviewed findings from 11 of those detailed studies (Exhibit 29). This shows a weighted technical potential of 29 percent in the US commercial sector (36 percent for power and 20 percent for natural gas). The potential with an internal rate of return above 10 percent comes out at 17 percent (20 percent for power and 14 percent for natural gas). One should interpret these numbers as a range rather than as point estimates, since the methodologies of the underlying studies may vary.[16] The Department of Energy (DOE) study,[17] which finds a 19 percent demand-abatement potential versus a business-as-usual scenario, confirms this range. In addition, its bottom-up findings by type of end use are in line with the ACEEE study, with greater potential for power-intensive end uses such as space cooling or lighting than for natural-gas-intensive end uses such as space and water heating (Exhibit 30).

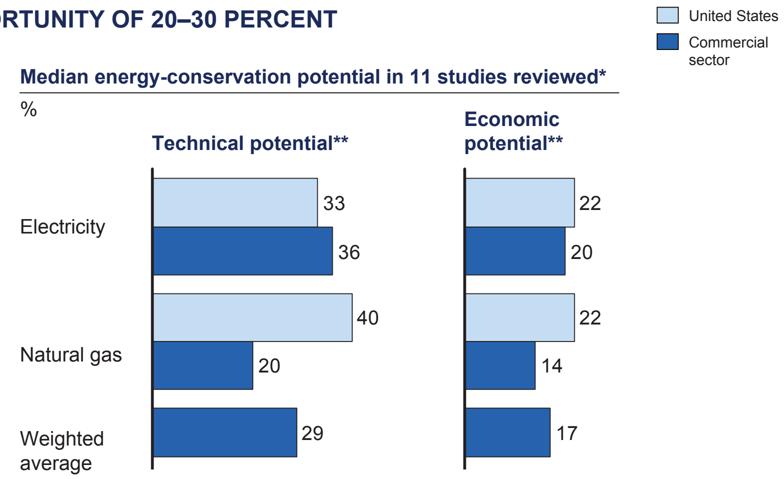
The potential in Northwestern Europe is slightly below that in the United States (20 percent versus 25 percent). We used a 2005 study by the Wuppertal Institute that shows a 23 percent potential by 2020 versus the business-as-usual

16 For example, the definition of positive economic returns can be based on utility economics (low range) or societal economics (high range).

17 *Scenarios for a Clean Energy Future*, US Department of Energy's Interlaboratory Working Group, 2000.

## Exhibit 29

### STUDIES HAVE IDENTIFIED A US ENERGY PRODUCTIVITY OPPORTUNITY OF 20–30 PERCENT



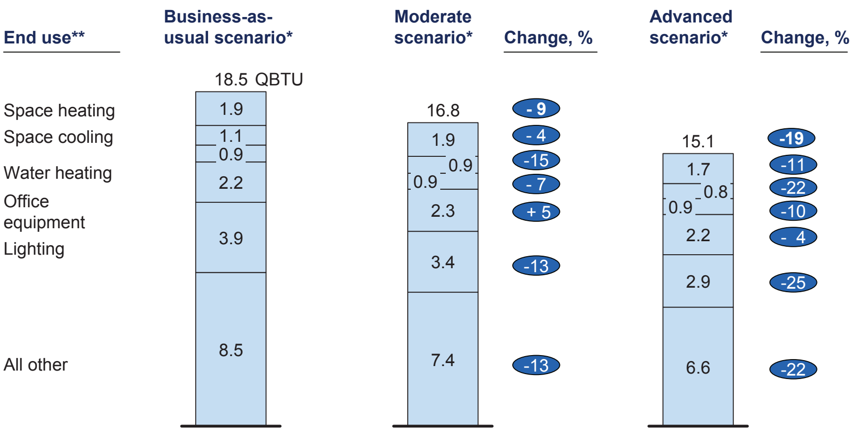

* Eleven studies carried out in many regions—California, Massachusetts, New York, Oregon, Utah, Vermont, Washington, the Southwest, the United States as a whole.

** This chart includes only the longest time periods and more aggressive scenarios covered in each study. Technical potential includes all measures examined, regardless of economics. Economic potential may be based on utility economics (low range) or societal economics (high range).

Source: ACEEE 2004

## Exhibit 30

### THE DEPARTMENT OF ENERGY'S INTERLABORATORY STUDY CONFIRMS THIS POTENTIAL IN THE UNITED STATES



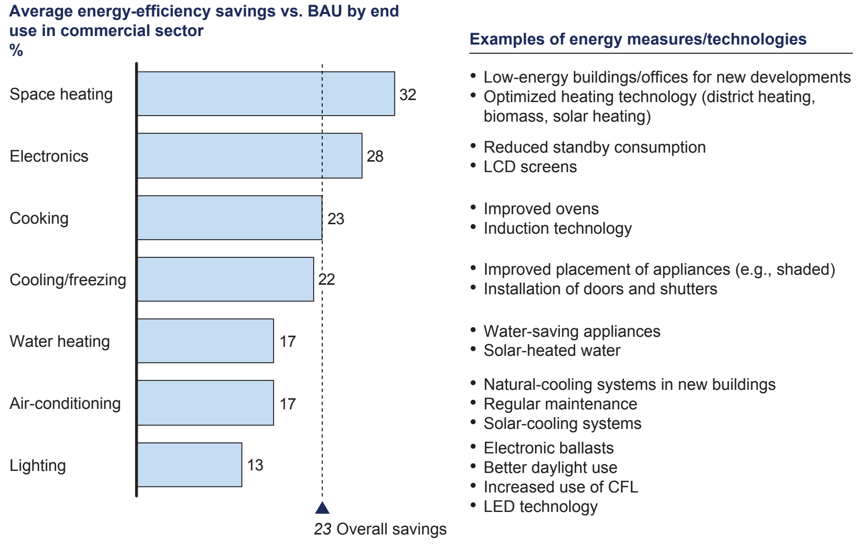

* The BAU forecast assumes a continuation of current energy policies and a steady pace of technological progress. In contrast, the Moderate and Advanced scenarios are defined by more innovative technologies and more aggressive policies.

** Energy demand considered here is primary consumption including power losses.

Source: Interlaboratory Working Group. 2000. Scenarios for a Clean Energy Future (Oak Ridge, TN; Oak Ridge National Laboratory and Berkeley, CA; LBNL) scenario (Exhibit 31). However, this study considers a broader array of high-efficiency technology options, which can give a higher potential. Such is the case for space heating, which lists some technologies that either require significant infrastructure investment (district heating) or are still not technologically mature (biomass and solar heating). We therefore adjusted the potential slightly downward.

**Exhibit 31**

**IN EUROPE THE ENERGY PRODUCTIVITY POTENTIAL STANDS AT 20 PERCENT**



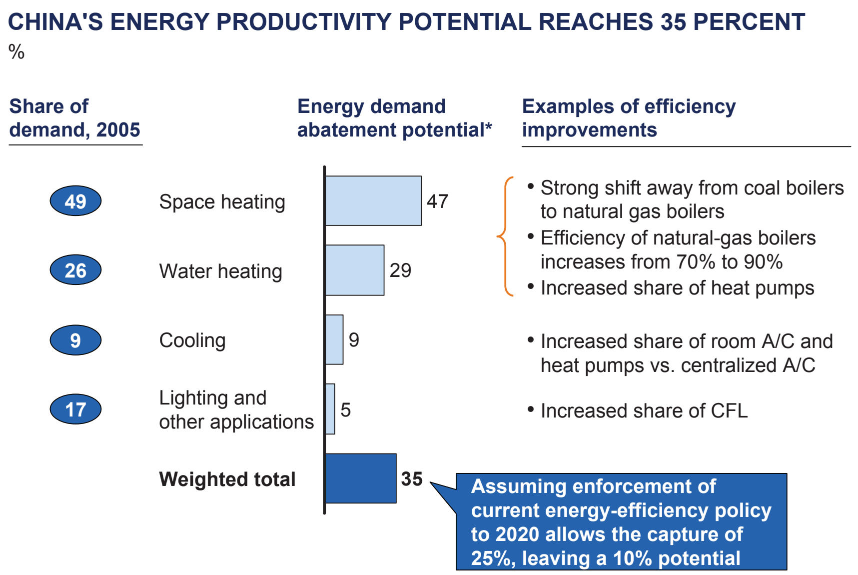

Source: Wuppertal Institute 2005

For China, we rely on LBNL China Energy Group research, which shows an annual efficiency improvement of 1.5 percent annually in the base case (Exhibit 32). This implies a 60 percent capture rate of the region's 35 percent improvement potential, reflecting both the high share of growth (two-thirds of commercial buildings operating in China in 2020 have not yet been built today) and the assumption that China will enforce current energy-efficiency laws to 2020. Yet beyond this rapid base case improvement rate, a further 10 percent energy productivity improvement opportunity remains untapped.

We based our analysis of China's potential on the LBNL China Group's detailed assumptions for China's commercial sector—a 35 percent demand-abatement potential compared with a business-as-usual scenario, mainly driven by sizable opportunities for space- and water-heating end uses that currently represent 75 percent of the sector's total energy demand. Space heating, for example, shows a 90 percent efficiency-improvement potential, which, in turn, produces a

47 percent demand-abatement potential. This high figure is based on a double "catch-up" assumption—i.e., that by 2020 both the efficiency and market shares of different types of space-heating technologies used in the Chinese commercial sector will converge to their current level in Japan. As illustration, the average efficiency of heat pumps would double and their market share would rise from less than 1 percent to more than 10 percent.

**Exhibit 32**




* As an example, doubling energy efficiency for a given end use leads to a demand reduction of 50%.
Source: LBNL, China Energy Group; MGI analysis

For other developing regions, we have used China's commercial sector's demand-abatement potential. However, given the fact that China achieved higher energy-efficiency gains in 1980–2000 than most developing regions, we adjusted this potential upward to 50 percent, assuming that other developing regions will, to an extent, play catch-up.

### Barriers to higher energy productivity

A significant share of the potential for energy productivity improvement with a positive internal rate of return (IRR) has been available for a long time but has still not been captured. Since most actors in the commercial sector are organizations, both private and public, that need to manage their costs, the fact that they have left so many economic investments on the table may seem even more surprising than in the highly fragmented residential sector. However, as in other sectors, a number of obstacles stand in the way of optimal resource allocation (Exhibit 33).

## Exhibit 33

### ENERGY USERS AND "UPSTREAM" DECISION MAKERS FACE OBSTACLES TO CAPTURING THIS POTENTIAL

■ Most important obstacles in developing regions

| | Obstacle | Key issues |
|---|---|---|
| Energy users | **• Not knowing** | **• Aggregate metering and billing for all appliances**<br>**• Reliability and ease of access to information** |
| | • Not caring | • Energy only a small part of the cost of owning and operating a device or building—e.g., gains from TV standby efficiency = $5/TV per year |
| | **• Capital constraints** | **• Immediate disbursement for future returns** |
| | • Split incentives | • Purchaser or operator of building/appliance distinct from entity paying energy bill—e.g., landlord/tenant relationship |
| Manufac-turers, builders, designers, and suppliers | • Reluctance to change | • Organizational inertia; design and production cycle |
| | • Inability to capture full benefits of R&D | • Difficulty protecting intellectual property; visibility of returns for fundamental research<br>• Reverse-fee structures for engineers and architects—e.g., fee as percentage of capital cost leads to oversizing of HVAC systems |

Source: *Scenarios for a Clean Energy Future*, Interlaboratory Working Group, 2000.

A review of the available literature reveals that these "market failures" have already been the object of comprehensive studies—we used a particularly useful synthesis of their description and classification in the DOE's *Scenarios for a Clean Energy Future* (2000). The study makes a distinction between obstacles faced by energy users themselves and those faced "upstream" by manufacturers, builders, and designers. For energy users, these hurdles act as a series of filters in the investment-decision process. For instance, users might not know enough about their own energy consumption to identify those end uses that would net them significant gains from improving efficiency; and even if they do, they may not have access to enough or appropriate information to identify improvement opportunities. Supposing they do, they might, in reality, not care about achieving greater efficiency, either because energy costs are a very small fraction of their total cost base, or because another entity will reap the savings—say a landlord rather than a tenant.

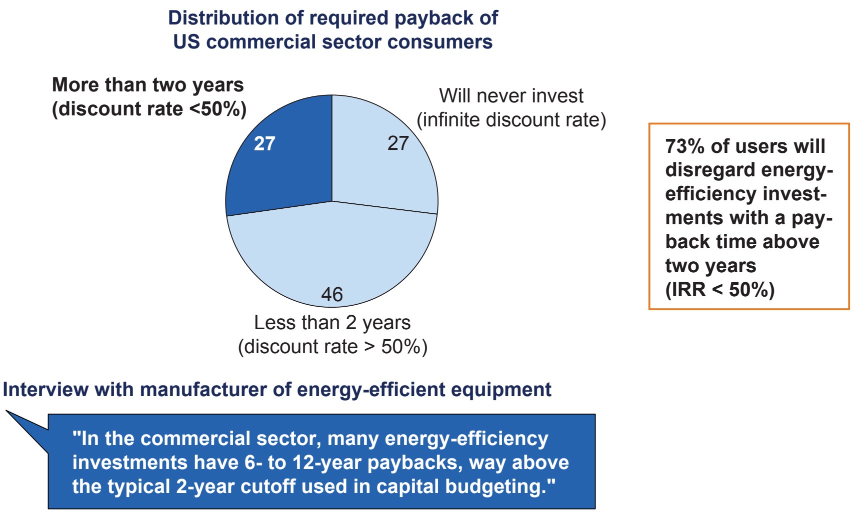
Even those investment opportunities that successfully pass through these filters can still face more constraints. For example, nearly three-quarters of energy users in the commercial sector require payback of less than two years on their investments[18] (Exhibit 34). At the same time, however, many energy productivity opportunities have 6- to 12-year paybacks. This means they fall to the bottom

18 This calculation is based on EIA's assumptions on the distribution of commercial sector discount factors.

of the priority list in the typical capital expenditure budget-allocation process. Furthermore, a large number of energy users, especially in the "MUSH" sectors (municipalities, universities, schools, and hospitals), operate under strong capital constraints that act as an additional barrier to investment. In the United States and a few other countries, specialized energy-services companies (ESCOs) are trying to bridge this gap by providing funds for the upfront investment in exchange for a share of the cash flow generated by energy savings. However, at approximately $2 billion per year in the United States, this industry remains small relative to the size of the opportunities available. Moreover, it does not seem set for strong growth, since, in the words of a senior executive at one of these companies, "our institutional clients' main motivation is not to save energy but to overcome the capital shortage they typically face to replace equipment and maintain buildings" (Exhibit 35).

**Exhibit 34**

**HIGH HURDLE RATES REDUCE THE AMOUNT OF EFFICIENCY INVESTMENTS**



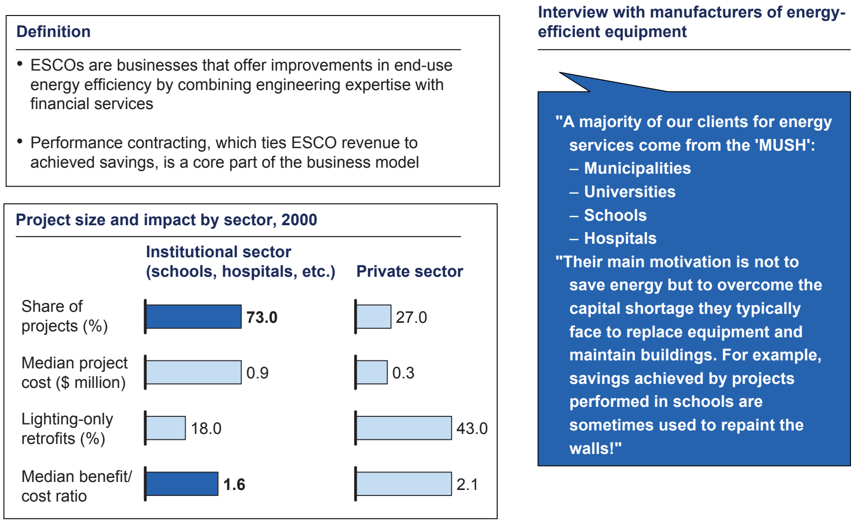

Source: EIA NEMS Commercial Model Documentation, 2005; disguised client interview, May 2006

## Capturing the energy productivity opportunity

The MGI energy productivity potential available for capture is determined on a 2020 horizon. The reason for considering such a long-term horizon is that a large share of efficiency-improvement opportunities (e.g., building shell upgrades) require substantial capital investment, and therefore only break even in new construction rather than in existing building retrofits. Given the long life span of buildings (50 years in many regions), and the resulting low turnover of the building stock, capturing the potential is a long-term process, even in regions with high floor-space growth such as China.

**Exhibit 35**

**COMMERCIAL SECTOR CONSUMERS WHO INVEST IN ENERGY EFFICIENCY OFTEN DO SO FOR NONENERGY REASONS**




Source: *Review of US ESCO industry market trends: an empirical analysis of project data*, LBNL; disguised client interview; MGI analysis

In periods when strong energy productivity gains have been achieved in the commercial sector, they can be traced back to regulatory intervention. One such period was observed in the United States in the aftermath of the second oil shock in 1979, when, between 1979 and 1986, energy intensity dropped by close to 4 percent per year in US commercial buildings (Exhibit 36). This followed the introduction of minimum-efficiency standards for key end uses in the late 1970s and their subsequent tightening in the first half of the 1980s. An example of the effectiveness of such policies was the 50 percent reduction in the energy intensity of commercial lighting between 1973 and 1985 (Exhibit 37). There was a similar experience in the road-transportation sector, where unprecedented fuel-economy gains were driven by the introduction of CAFE standards over the same period.

In view of such examples, we therefore base our regional capture-rate scenarios going forward on energy-efficiency policies and measures such as building codes and mandatory efficiency standards.

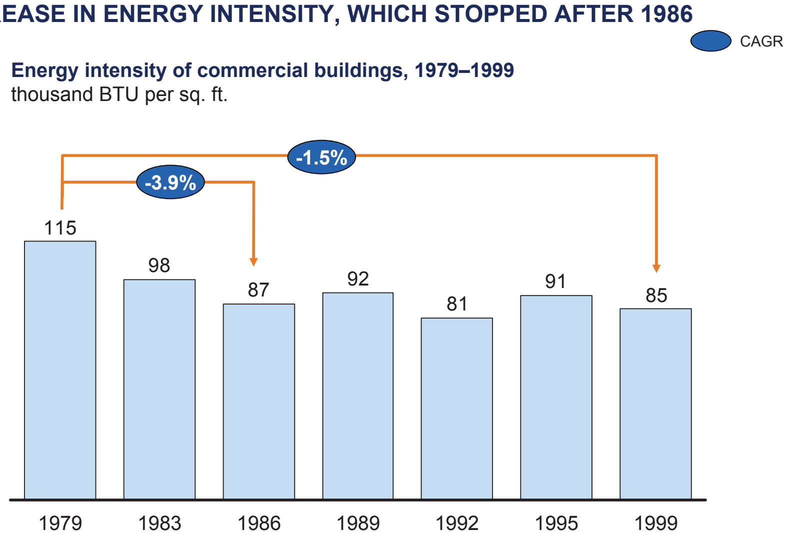
**Energy-efficiency policy assumptions**

Based on existing reviews of energy-efficiency policies and on the results of past policies, Northwestern Europe and Japan currently seem positioned to achieve

## Exhibit 36

### IN THE UNITED STATES, ENERGY-PRICE SHOCKS TRIGGERED A RAPID DECREASE IN ENERGY INTENSITY, WHICH STOPPED AFTER 1986

**Energy intensity of commercial buildings, 1979–1999**
thousand BTU per sq. ft.

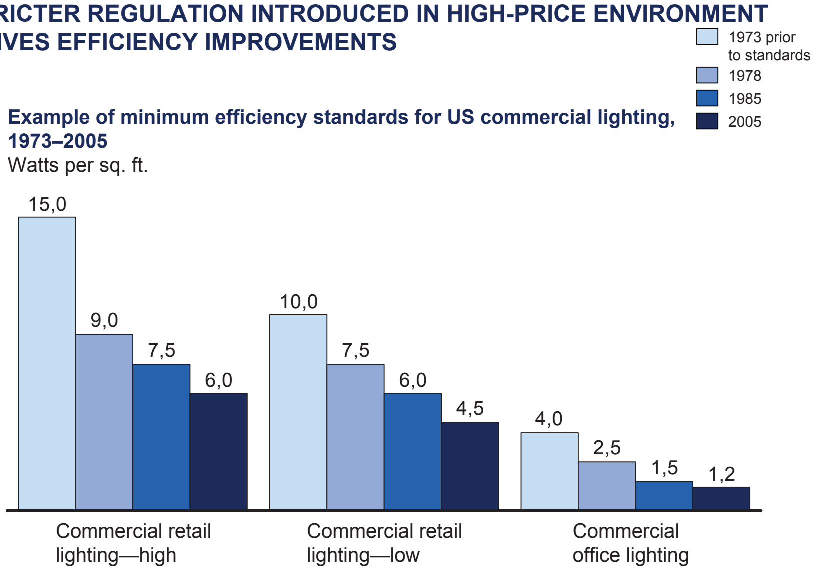



Source: EIA CBECS; MGI analysis

## Exhibit 37

### STRICTER REGULATION INTRODUCED IN HIGH-PRICE ENVIRONMENT DRIVES EFFICIENCY IMPROVEMENTS

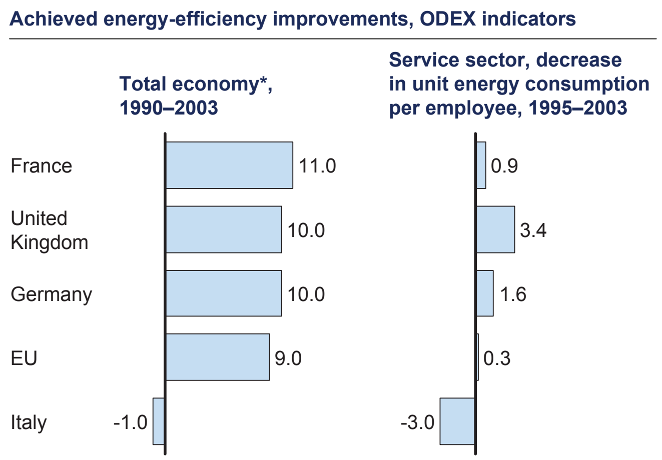
**Example of minimum efficiency standards for US commercial lighting, 1973–2005**
Watts per sq. ft.




Source: *From the Lab to the Marketplace: The Role of California's Energy Policies, California Lighting and Technology*, Center 2nd Annual Forum, May 9-10, 2005, Arthur H. Rosenfeld, Commissioner, California Energy Commission the highest capture rates in their respective commercial sectors. The available indicators of energy-efficiency improvements support this view—France, the United Kingdom, and Germany all achieved efficiency improvements of some 10 percent in 1990–2003; in contrast, Italy saw a 1 percent efficiency decrease in the same period. Their ratios of unit energy consumption per employee in the commercial sector experienced a modest decrease in 1995–2003; again, Italy provides a contrast, with a 3 percent increase (Exhibit 38). In Japan, commercial sector energy intensity[19] declined by 25 percent in the 1970s and has remained constant since then, despite higher penetration of power-intensive end uses such as air-conditioning and office equipment (Exhibit 39).

**Exhibit 38**

**IN WESTERN EUROPE, RECENT ENERGY-EFFICIENCY PERFORMANCE SUGGESTS NATIONAL CAPTURE RATES WILL LIKELY VARY**
%




* Adjusted for differences in climate.
Source: Enerdata Odysee database; MGI analysis

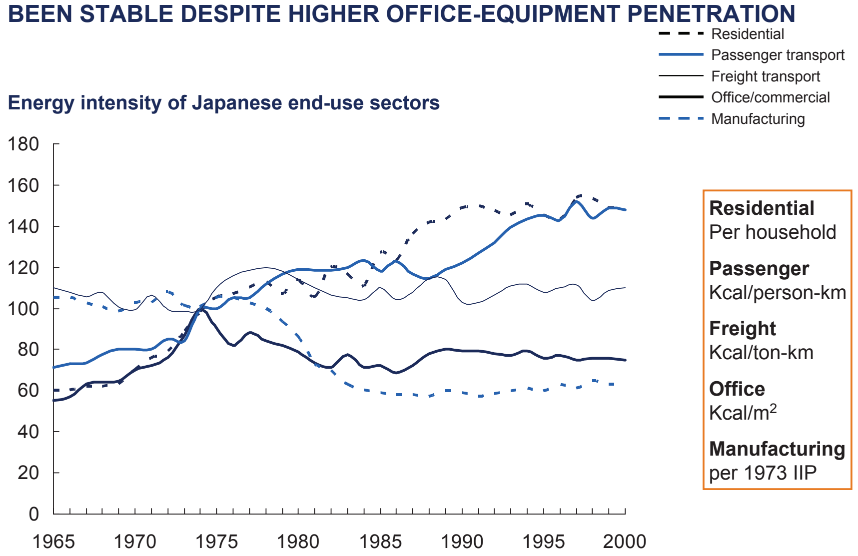
Within Northwestern Europe, a number of countries have taken the lead in designing and implementing active energy-efficiency policies that are explicitly linked to their commitment to reducing greenhouse-gas emissions as signatories to the Kyoto protocol to the UN Framework Convention on Climate Change. The United Kingdom, for example, has made a commitment to cut emissions 20 percent by 2010 and 60 percent by 2020. The UK government unveiled a detailed Energy Efficiency action plan in 2004, and has already implemented several regulatory measures to reduce demand and the resulting emissions. These measures span the whole range from better information to taxation: information and advice

19 We arrive at an approximation from kcal consumed per square meter of office space.

programs through the Energy Saving Trust, aggressive demand-side-management programs run by utilities, tightening of building codes, and a Climate Change Levy for the business and public sectors (i.e., a carbon tax). The UK government also plans to lead by example by aggressively promoting efficiency in public buildings, which fall within the scope of the commercial sector.

**Exhibit 39**

**JAPAN'S COMMERCIAL ENERGY INTENSITY FELL IN THE 1970S; HAS BEEN STABLE DESPITE HIGHER OFFICE-EQUIPMENT PENETRATION**




Source: METI and The Institute of Energy Economics, Japan

In Japan, also committed to strongly reducing its emissions, a number of programs have been set up and strengthened over time to help capture the efficiency potential, again spanning the whole range from information to mandatory standards:

- Requirement to establish energy-management systems and appoint energy managers (1979);
- Detailed energy conservation labeling system (2000);
- Promotion of IT-based building energy-management systems;
- Promotion of energy-services companies (ESCOs);
- Voluntary action plans coordinated by the Keidanren business federation (1997);
- Mandatory “Top Runner” program, under which manufacturers are requested to improve the energy efficiency of their products to the top level of the benchmark within a specified period (1999).

In contrast, the energy-efficiency policies being considered in the United States at the federal level as of May 2005 will not have a major impact on energy demand. The EIA has modeled a wide range of standards, codes, and tax incentives considered by US policy makers, and shown that they would have a limited impact of minus 0.1 percent per year on demand over 2006–2025 (Exhibit 40). However, EIA's analysis also shows that extending energy efficiency performance standards (EEPS) for natural-gas and electricity suppliers would lead to an 8.6 percent demand reduction by 2025 versus the reference case (Exhibit 41). These programs would build on or replace "public benefits" energy efficiency programs introduced in the late 1990s. Evidence from states where these programs have already been introduced indicate that they could lead to savings close to 1 percent a year, bringing the United States much closer to capturing its full energy potential than in the current policy environment (Exhibit 42).

**Exhibit 40**

## TIGHTER US FEDERAL STANDARDS AND TAX INCENTIVES WILL NOT HAVE A MAJOR IMPACT ON ENERGY DEMAND ON THEIR OWN

**Policy impacts relative to the AEO2005 reference case**
QBTU

| | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|
| **Primary energy use (commercial)** | 20.29 | 22.18 | 24.24 | 26.74 |
| **Change in energy use by policy** | | | | |
| Air-conditioner efficiency standard | (0.01) | (0.05) | (0.08) | (0.10) |
| Refrigerator efficiency standard | (0.00) | (0.00) | (0.01) | (0.01) |
| Prerinse spray valve standard | (0.05) | (0.08) | (0.08) | (0.08) |
| Distribution-transformer standard | 0 | 0 | 0 | 0 |
| Equipment tax deductions | (0.01) | (0.00) | (0.00) | (0.00) |
| Building codes | (0.09) | (0.24) | (0.38) | (0.53) |
| *Total* | *(0.17)* | *(0.43)* | *(0.65)* | *(0.86)* |
| **Energy use after policy** | 20.14 | 21.81 | 23.70 | 26.03 |
| **Total impact by policy** | -1% | -2% | -3% | -3% |

- The EIA has modeled a wide range of energy-efficiency policies considered by US policy makers
- Standards, codes, and tax incentives will have a **limited impact of -0.1% per year over 2006–2025**

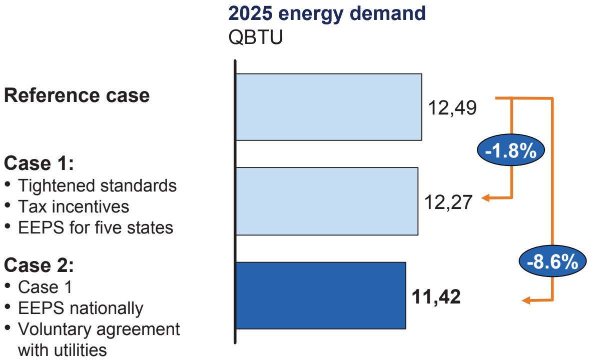
Source: EIA analysis, 2005

China has recently introduced or strengthened several energy-efficiency policies, including specific policies for commercial buildings such as building codes, office equipment standards and labeling programs, reform of heat metering and pricing, as well as government procurement. We have opted to assume that these policies are implemented and that the targets set out in the 11th Five-Year Plan are met by 2020. However, it is beyond doubt that implementation remains a major challenge. Building codes offer an interesting example: only a few major cities, such as Shanghai, have implemented them, and recent estimates put the

## Exhibit 41

### BY CONTRAST, US ENERGY-EFFICIENCY PERFORMANCE PROGRAMS (EEPS) FOR UTILITIES COULD HAVE A MAJOR IMPACT ON DEMAND

**Impact of multipolicy cases on delivered energy demand, as modeled by EIA**




Source: EIA analysis, 2005

## Exhibit 42

### EEPS WOULD BUILD ON OR REPLACE "PUBLIC BENEFITS" ENERGY-EFFICIENCY POLICIES OF THE LATE 1990S

**Public benefits energy-efficiency policies**

**Context**
- Until the 1990s, regulated utilities provided "public benefits"
  - Energy efficiency
  - Renewable energy
  - Low-income programs
  - Public-interest-oriented R&D
- However, electric-industry restructuring led many utilities to abandon these services
- In reaction to this, formal funding mechanisms to support public benefits grew in late 1990s (18 states in 2004)

**Funding**
- Most commonly, a "public benefits" per kWh charge on the electric distribution service
- Long-term funding ranging from 0.03 to 3 mills/kWh

**Adminis-tration**
- Utility
- Government agencies
- Independent nonprofit organization

**Achieved savings and budgets, 2002 or 2003**

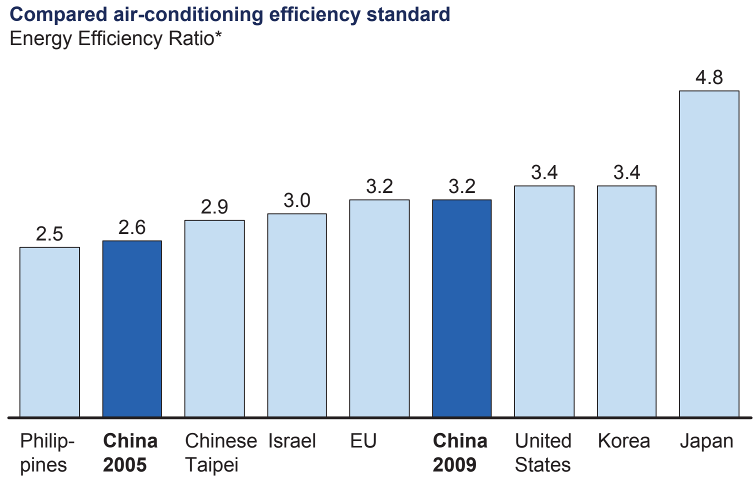
| State | Savings achieved % of utility sales* | Budget % of utility revenues* |
|---|---|---|
| Vermont | 0.8 | 3.3 |
| Connecticut | 0.8 | 3.1 |
| Rhode Island | 0.8 | 2.7 |
| California | 0.8 | 1.5 |
| Massachusetts | 0.7 | 3.0 |
| Wisconsin | 0.4 | 1.4 |
| New York | 0.3 | 1.3 |
| New Jersey | 0.2 | 1.5 |
| Texas | 0.2 | 0.4 |

* Based on revenues and sales of utilities affected by public benefits funding requirements.

Source: *Five Years In: An Examination of the First Half Decade of Public Benefits Energy Efficiency Policies*, ACEEE, 2004 nationwide compliance rate for new construction below 5 percent. Even when they are implemented, Chinese building codes remain less strict than comparable codes in developed regions, leading, for example, to higher unit-space heating-energy consumption. The same is true for key minimum-efficiency standards such as those for air-conditioning. Despite the fact that these are projected to increase in 2009, Chinese standards will remain below current US, Korean, and Japanese standards (Exhibit 43). It would be easier for China to fulfill its energy-efficiency ambitions if it both tightened its standards and strengthened their enforcement.

**Exhibit 43**

**CHINESE AIR-CONDITIONING EFFICIENCY STANDARDS WILL GRADUALLY RISE BUT STAY BELOW US AND JAPANESE STANDARDS**



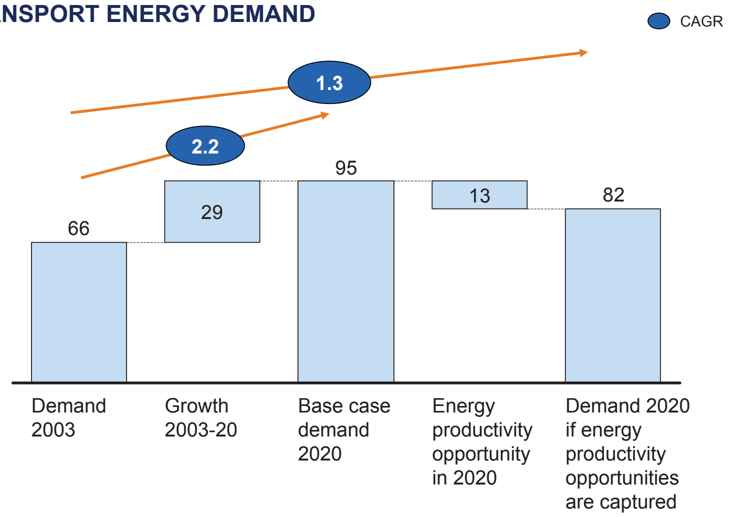

* The higher the EER rating, the more energy efficient is the air conditioner.

Source: LBNL, China Energy Group

## Road-transportation sector's energy demand is most sensitive to oil prices

- Consumers respond to changes in fuel price: US light-vehicle fuel demand is almost 20 percent lower in a $70 oil-price scenario by 2020 than at $30 a barrel.
- China and the Middle East will together contribute 39 percent of total road-transportation fuel demand growth to 2020—a higher share than the 37 percent of the United States and Europe combined.
- Base-case vehicle stock in China grows at close to 10 percent annually to 2020, from 25 million vehicles in 2003 to 120 million vehicles in 2020.
- Driving one mile in the United States requires 37 percent more fuel on average than in Europe, due to larger vehicle size and less efficient engine technology. By 2020, this gap will widen to 42 percent.
- In oil-exporting regions, fuel demand increases along with the oil price under current policies: oil revenues boost GDP growth, while subsidies maintain low fuel prices for consumers. Middle East fuel-demand growth increases from 3.4 percent to 5.3 percent per annum between the $30- and $70-oil scenarios.

**ROAD TRANSPORT ENERGY DEMAND**
QBTU




| | | | | | |
|---|---|---|---|---|---|
| **Global total** % | 16 | 15 | 15 | 10 | 17 |

Source: MGI Global Energy Demand Model

# Road-transportation sector

## I. EXECUTIVE SUMMARY

Road transportation is the largest oil-consuming sector globally, so it is critical for understanding the impact of high oil prices on global energy demand. Consumers, when exposed to sustained high oil prices, cut back their fuel consumption by driving less and by purchasing more fuel-efficient vehicles. However, a large proportion of consumers worldwide are shielded from changes in the oil price by subsidies, leaving room for substantial energy productivity improvement opportunities.

MGI's base case is that end-use energy demand from road transportation grows by 2.2 percent annually to 2020, with the fastest growth coming from China (6.3 percent) and the Middle East (4.6 percent). In contrast, demand grows moderately in the United States and Europe at 1.5 percent and remains flat in Japan. Developing regions as a whole overtake developed regions in terms of demand by 2010. Over the period 2003–2020, they contribute close to three-quarters of the sector's growth.

Both GDP growth and the oil price impact road-transportation fuel demand: annual demand growth to 2020 could swing between 1.2 percent in a low GDP-growth, $70-oil environment, and 2.9 percent in a high GDP-growth, $30-oil environment. GDP growth impacts vehicle stock growth, either through the elasticity of sales or through the elasticity of vehicle penetration. In China, for example, higher GDP growth would further boost the explosive growth rate of the vehicle stock to reach 170 million vehicles in 2020, up from a mere 25 million in 2003.

The first impact of oil price—to the extent that it is reflected in consumer fuel prices—is on miles driven. In a sustained $70-oil scenario, US and European consumers drive 12 percent and 5 percent fewer miles, respectively, in 2010 than in a $30-oil scenario. In contrast, driving remains unchanged in regions with high fuel subsidies such as the Middle East. Over time, an additional impact comes from fuel-economy improvements as consumers shift to more fuel-efficient vehicles. Although a number of shock absorbers muted the response to high oil prices in the period from 2003 to 2005, recent evidence suggests these are now wearing off.

Overall, the available energy productivity opportunities in road transportation stand at 6.5 million barrels per day versus base-case 2020 fuel demand. To capture these opportunities, policy makers could use a combination of measures, such as removing subsidies, increasing road-transportation fuel taxes, raising fuel-economy standards, and encouraging the development of the hybrid-vehicle market through consumer tax breaks and incentives for auto manufacturers.

## II. ROAD-TRANSPORTATION-SECTOR ENERGY DEMAND SIZE, GROWTH, AND FUEL MIX

### Size and regional breakdown of energy demand, 2003

Road transportation is by far the largest oil-consuming sector globally—with 32 million barrels of products per day, it represented 46 percent of global final petroleum-products demand in 2003. In terms of global end-use demand in 2003, road transportation represented 16 percent with 61 QBTUs of final demand and 5 QBTUs of allocated refining losses.[1] In contrast to sectors like residential and commercial, road transportation's share of global end-use demand is lower than its 19 percent share of global final energy demand (Exhibit 1). This is due to the fact that 90 percent of transformation losses occur in power generation, and are allocated to power-intensive sectors.

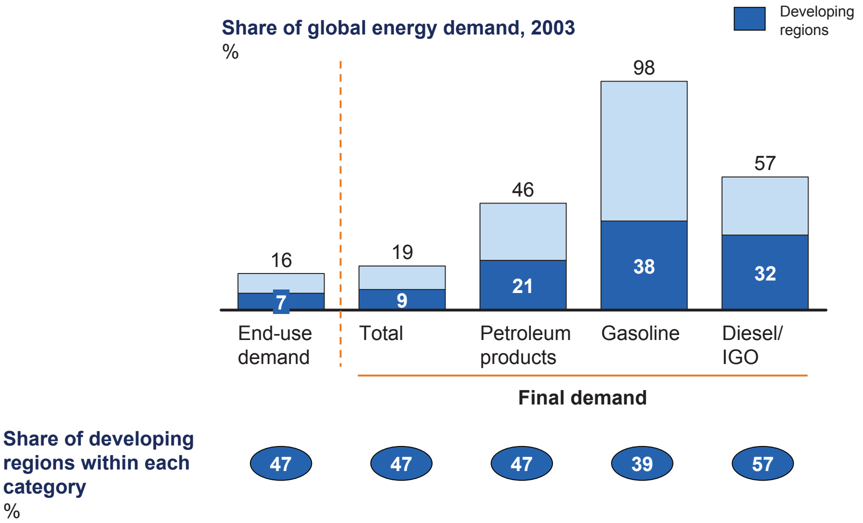
Breaking 2003 road-transportation energy demand into regions, more than half came from developed regions, with the United States contributing 34 percent, Northwestern Europe 11 percent, Japan 5 percent and Canada 3 percent. Demand among developing regions was more fragmented, with no region representing more than 6 percent of global demand except developing Europe.[2] Interestingly, demand in China and in the Middle East, both regions set for strong growth, was the same size in 2003 (Exhibit 2).

1 End-use demand considers the allocation of transformation losses to end-use sectors (e.g., refining losses for petroleum products, conversion losses for power).

2 This includes Mediterranean-North Africa (9 percent) and Baltic/Eastern Europe (2 percent).

## Exhibit 1

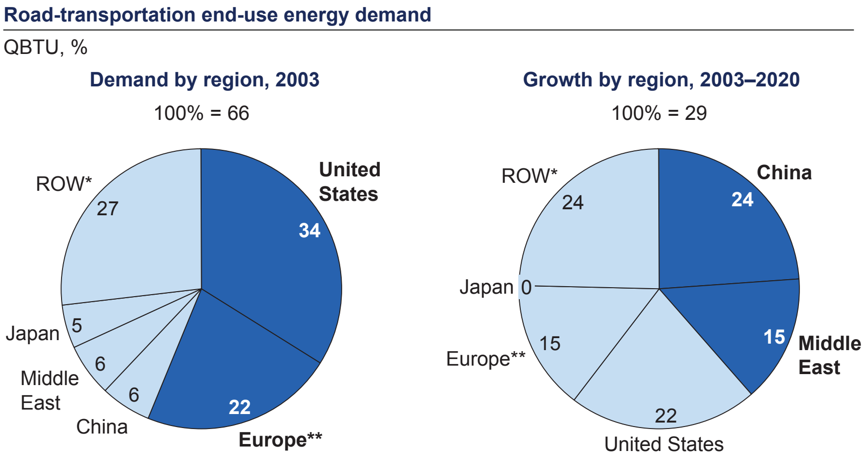
### ROAD TRANSPORTATION REPRESENTS 16 PERCENT OF GLOBAL END-USE DEMAND AND 46 PERCENT OF PETROLEUM-PRODUCTS DEMAND




Source: International Energy Agency (IEA); MGI analysis

## Exhibit 2

### THE UNITED STATES AND EUROPE REPRESENT 56 PERCENT OF ROAD-TRANSPORTATION ENERGY DEMAND IN 2003, AND CHINA AND THE MIDDLE EAST 39 PERCENT OF ENERGY DEMAND GROWTH TO 2020



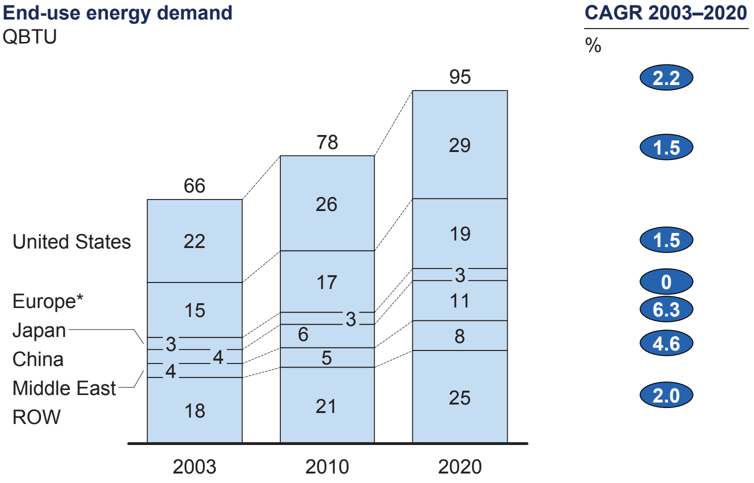

* Rest of the world.
** Including Northwestern Europe (11%), Mediterranean and North Africa (9%), and Baltic/Eastern Europe (2%).
Source: MGI Global Energy Demand Model

## Growth of energy demand and $CO_2$ emissions

Our base case is that end-use energy demand grows at 2.2 percent annually to 2020—a 29 QBTU increase from 66 to 95 QBTUs (Exhibit 3). The fastest growth takes place in China (6.3 percent per annum) and the Middle East (4.6 percent per annum). By contrast, demand grows moderately in the United States and Europe at 1.5 percent, and remains flat in Japan.[3] As a result, China and the Middle East together contribute 39 percent of the sector's total demand growth to 2020—a higher share than the United States and Europe combined (37 percent). This comparison is even more spectacular when one considers these regions' initial shares of demand: 56 percent for the United States and Europe, against only 12 percent for China and the Middle East.

**Exhibit 3**

ROAD TRANSPORTATION END-USE ENERGY DEMAND WILL GROW AT 2.2 PERCENT ANNUALLY TO 2020 – A 29 QBTU INCREASE




* Including Northwestern Europe, Mediterranean and North Africa, and Baltic/Eastern Europe.
Source: IEA; MGI Global Energy Demand Model

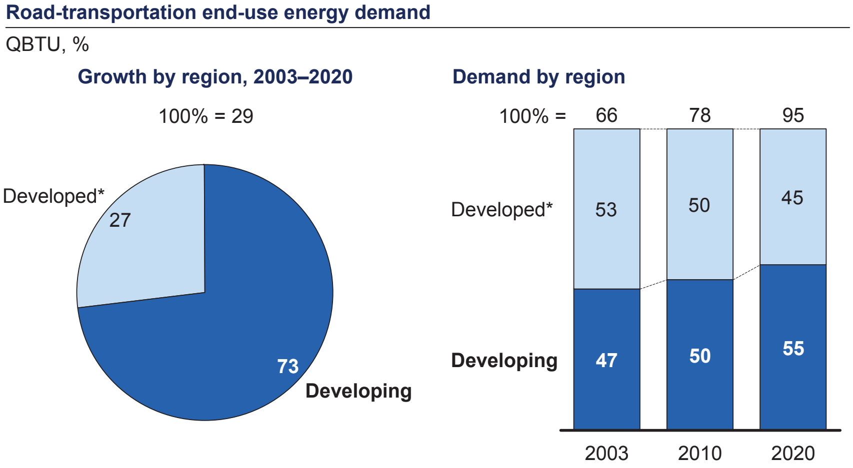
Developing regions as a whole overtake developed regions in terms of demand by 2010. By 2020, their share reaches 55 percent. Over the period 2003–2020, they contribute close to three-quarters of the sector's growth (Exhibit 4). Although high growth in China and the Middle East plays a very significant role, demand also grows at above 3 percent per annum in other regions such as Korea or India, albeit from a lower base. Compared to historical growth trends, however, higher growth in developing regions will not fully offset lower growth in developed

3 The detailed case-study results underlying these growth rates are presented at the end of this report.

regions. As a result, global demand growth will slightly decelerate compared with the period 1994–2003 (Exhibit 5).[4]

**Exhibit 4**

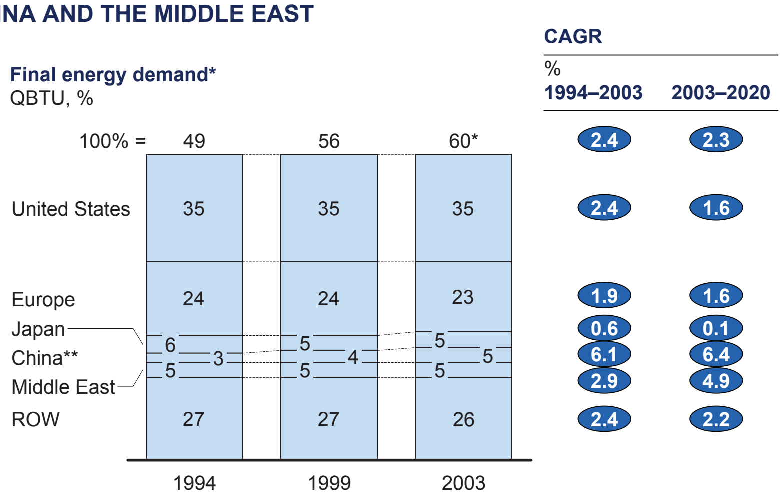
## DEVELOPING REGIONS WILL DRIVE CLOSE TO 75 PERCENT OF ROAD-TRANSPORTATION ENERGY DEMAND GROWTH TO 2020




* United States, Canada, Northwestern Europe, Japan
Source: MGI Global Energy Demand Model

**Exhibit 5**

## MGI'S PROJECTION IS SLIGHTLY BELOW THE HISTORICAL TREND, WITH SLOWER GROWTH IN THE UNITED STATES AND ACCELERATION IN CHINA AND THE MIDDLE EAST




* Due to data limitations, the comparison with historical growth trends is established for final energy demand.
** The IEA 2003 total differs from the MGI baseline due to adjustments to China's demand to reflect the LBNL reclassification of energy demand by sector.
Source: IEA; MGI Global Energy Demand Model

4 Due to data limitations, the comparison to historical growth trends is established for final energy demand.

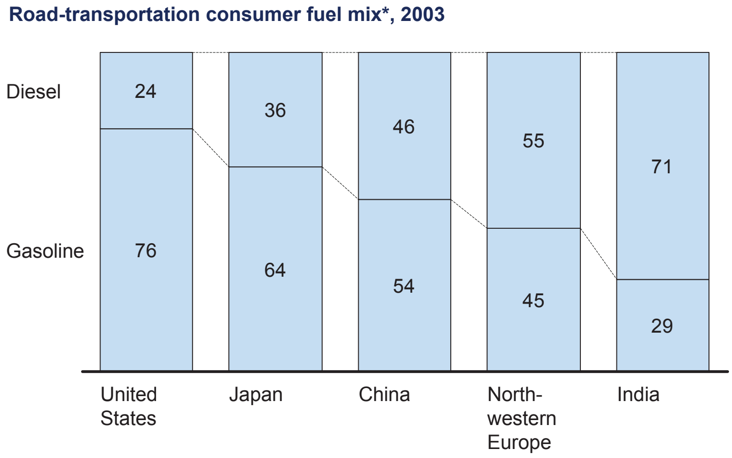
Overall, the sector's $CO_2$ emissions will grow from 4,600 million metric tons in 2003 to 6,700 million tons in 2020, a 2.2 percent growth rate that is in line with demand growth. The sector's share of total global $CO_2$ emissions will slightly decrease from 19.5 percent in 2003 to 18.9 percent in 2020.

**Sector consumer fuel mix**

The sector's fuel usage is split between gasoline and diesel.[5] Gasoline still dominates road-transportation consumers' choices globally, with 60 percent of demand in 2003, yet the fuel mix by region can vary significantly (Exhibit 6). Typically, gasoline tends to be the predominant fuel for passenger transportation (light vehicles, including light trucks in the United States), while diesel is used for commercial road transportation (trucks). The mix of fuel used in the sector reflects the share of passenger transportation by region, in turn strongly linked to the level of income per capita. As economies develop, a growing number of consumers gain access to light-vehicle ownership, thereby increasing the share of passenger transportation. The United States and Japan, the two regions with the highest income per capita, are also those with the highest share of gasoline.

**Exhibit 6**

**THE ROAD-TRANSPORTATION FUEL MIX VARIES ACROSS REGIONS DEPENDING ON THE SHARE OF PASSENGER TRANSPORT AND CONSUMER PREFERENCES**




* In this report, fuel mix reflects consumers' choices between gasoline and diesel vehicles. It does not include any assumptions regarding actual blending of motor fuels with ethanol or biodiesel.

Source: EIA; 2005 Handbook of Energy & Economic Statistics in Japan; L. Berkeley National Lab (LBNL); MGI analysis

Differences in relative tax treatment between fuels have also contributed to the choice of fuel for passenger transportation, as evidenced by the high share of

5 In this report, fuel mix reflects consumers' choices between gasoline and diesel vehicles. It does not include any assumptions regarding actual blending of motor fuels with ethanol or biodiesel.

diesel in Northwestern Europe (55 percent).[6] For a long time now, almost all the countries of continental Europe have applied lower taxes to diesel than to gasoline, and this has led to a retail-price advantage of between 10 percent and 25 percent for diesel compared with gasoline. In recent years, the region has become a stronghold of diesel cars, with penetration now reaching more than 50 percent on average in EU15 countries, and as high as 70 percent in France, Portugal, and Austria. Even for freight, the picture appears more complex. For example, in China, where freight still represents two-thirds of road-transportation demand, the overall share of gasoline is 54 percent, which implies that a significant proportion of commercial vehicles run on gasoline.

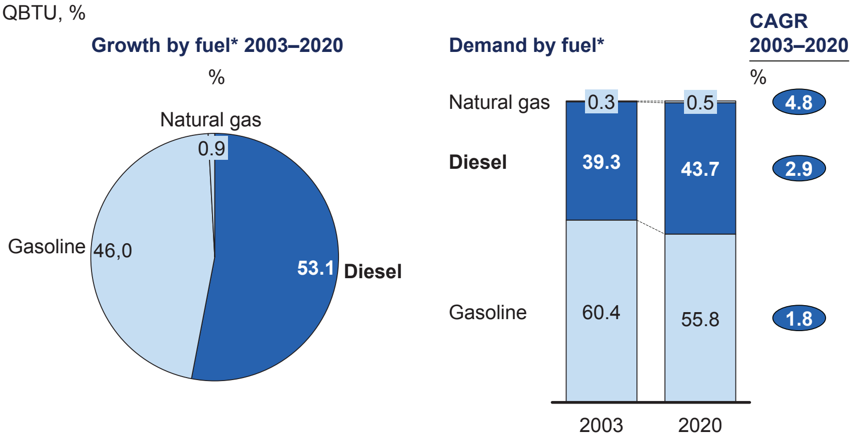
Diesel gains against gasoline in the MGI base-case scenario going forward. Its growth accelerates to 2.9 percent annually to 2020 compared with 1.8 percent for gasoline. Therefore, its share of the global fuel mix rises from 39.3 percent to 43.7 percent. The speeding up of diesel growth is due to an increasing share of diesel cars, especially in Europe, as well as to the lower price elasticity of diesel demand (due to higher subsidies and less elasticity in freight transportation). Although direct use of natural gas in vehicles running on compressed natural gas (CNG) grows even faster at 4.8 percent per annum, it remains marginal with a mere 0.5 percent of global demand in 2020 (Exhibit 7).

**Exhibit 7**

**DIESEL'S SHARE OF THE GLOBAL ROAD-TRANSPORTATION FUEL MIX WILL INCREASE**

**Road-transportation sector final demand**

QBTU, %




* In this report, fuel mix reflects consumers' choices between gasoline and diesel vehicles. It does not include any assumptions regarding actual blending of motor fuels with ethanol or biodiesel.

Source: MGI Global Energy Demand Model

6 Northwestern Europe includes Belgium, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Switzerland, and the United Kingdom.

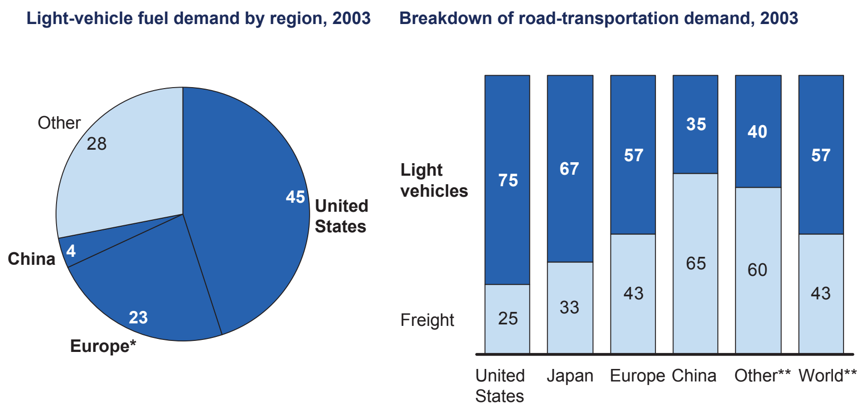
## III. DRIVERS OF ENERGY DEMAND

### Case-study methodology and sources

The MGI road-transportation regional case studies directly analyze light-vehicle demand in the United States and Europe, as well as light-vehicle and freight demand in China. Together, these three regions represent more than 70 percent of global light-vehicle fuel demand. Within regions, light-vehicle demand accounts for a majority of road-transportation demand in the United States (75 percent) and in Europe (57 percent), and for just over one-third in China (Exhibit 8).

**Exhibit 8**

**MGI ROAD CASE STUDIES COVER ~70 PERCENT OF LIGHT-VEHICLE FUEL DEMAND**
%

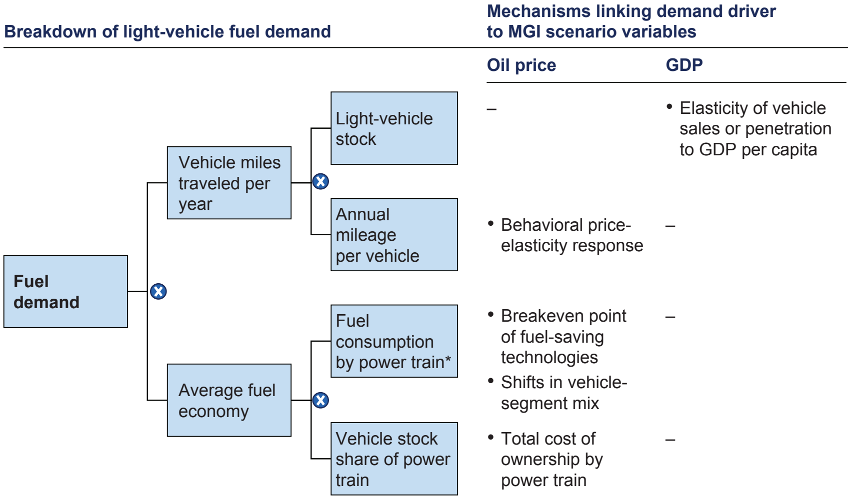



* Including the following regions: EU25, Turkey, and Russia.
** Estimates.
Source: IEA; EIA; 2005 Handbook of Energy & Economic Statistics in Japan; MGI analysis

### Light-vehicle fuel demand

The two microeconomic drivers of light-vehicle fuel demand are vehicle miles traveled and average fuel economy. To create bottom-up projections of demand growth, it is necessary to further decompose each of these drivers (Exhibit 9). Growth of miles traveled breaks down simply into growth of the light-vehicle stock and growth of average miles driven per vehicle. Projecting the evolution of average fuel economy is more complex, since it involves both the average fuel consumption by power train (internal combustion or hybrid engine, gasoline or diesel) and the share of each power train. We also weight average fuel consumption across light-vehicle segments: a higher oil price increases the share of cars versus light trucks, as well as the share of smaller vehicles in each category. The evolution of these drivers varies significantly by region.

## LIGHT-VEHICLE FUEL DEMAND IS DRIVEN BY MILES TRAVELED AND AVERAGE FUEL ECONOMY – THEMSELVES LINKED TO OIL PRICE AND GDP GROWTH




* Fuel consumption is also weighted across light-vehicle segments (e.g., cars vs. light trucks in the United States).
Source: MGI analysis

In order to obtain the full set of MGI demand scenarios, we link the following four drivers explicitly to our "macro" scenario variables—GDP growth and oil price—in the following ways:

- GDP impacts growth of the light-vehicle stock, either through the elasticity of sales (faster GDP growth means more cars are sold), or directly through the elasticity of vehicle penetration (higher GDP per capita means more cars per thousand inhabitants).

- Oil price impacts miles driven through behavioral elasticity—i.e., consumers drive less in response to higher fuel prices. The magnitude of this response depends on the fuel-pricing mechanism by region; those with high fuel subsidies such as the Middle East, for example, are not affected.

- Oil price also changes the economics of fuel-saving technologies: higher fuel prices increase the monetary value of fuel savings, meaning that more technologies break even from a consumer standpoint. In the same way, higher fuel prices also favor high-efficiency power trains such as diesel internal combustion engines (ICE-diesel) or hybrids, since the initial premium for their purchase becomes smaller relative to fuel savings.

**Approach for remaining demand**

Outside the MGI case studies are demand for freight for all regions, as well as light vehicles outside the United States, Europe, and China. We build regional projections using multipliers between GDP growth and fuel-demand growth (Exhibit 10). We first derive these multipliers from historical data for the period 1994–2003 and then adjust them. When comparing historical multipliers to GDP per capita across regions, we identified an S-curve pattern along the path of economic development. Initially, households cannot afford cars, so the multiplier is low and only increases after a certain threshold of income (around $5,000 PPP per capita), as consumers start purchasing vehicles. It can reach a value above 1, meaning that fuel-demand growth outpaces GDP growth. However, once income per capita reaches a higher threshold (between $15,000 and $20,000 PPP per capita), car penetration reaches saturation and the multiplier decreases again. Going forward, we used projections of GDP PPP per capita by region to adjust historical multipliers. Eastern Europe, for example, has a high historical multiplier reflecting a "catch-up" of car penetration after the end of Communism, yet we use a lower multiplier closer to the current one in EU15 countries. On the other hand, the Middle East keeps a multiplier above 1, reflecting the impact of high fuel subsidies, which lead to structurally much more intensive fuel consumption than seen elsewhere.

**Exhibit 10**

**OUTSIDE OUR CASE STUDIES, WE PROJECT FUEL-DEMAND GROWTH USING GDP MULTIPLIERS**

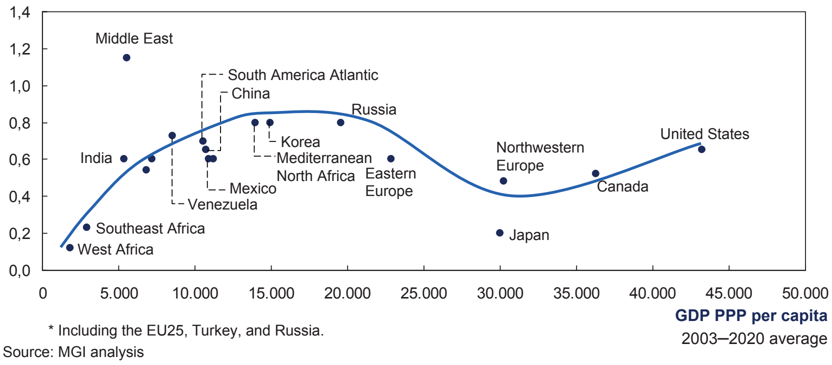
**Demand not covered by MGI case studies**

- Road-freight demand in all regions
- Light-vehicle demand in regions outside the United States., Europe* and China

**Methodology**

- Historical multiplier between GDP per capita and road-transportation fuel demand growth
- Adjustment to reflect vehicle penetration S-curve to 2020
- Price-elasticity impact on demand derived from case studies and applied based on regional fuel-pricing mechanisms

**Multiplier between GDP per capita and road-transportation energy demand 2003–2020**




* Including the EU25, Turkey, and Russia.

Source: MGI analysis

## UNITED STATES AND EUROPE LIGHT-VEHICLE CASE STUDIES

MGI's detailed case studies focus on the key drivers of fuel demand—the growth of the vehicle stock, average miles traveled per vehicle (VMT), and the average fuel economy of the vehicle stock. The combined evolution of these three factors determines the fuel-demand growth rate to 2010 and 2020, applied to our base year.[7] In this report we present the two scenarios—base GDP growth with a $50-oil price and a $70-oil price— that show the most acute shifts in the evolution of VMT and fuel economy. We present the synthesis of the findings of MGI's case study on the United States in Exhibits 11 and 12 and on Europe in Exhibits 13 and 14.

In the $50-oil scenario, light vehicle fuel-demand growth to 2020 is very similar in both the United States and Europe at 1.1 percent and 0.9 percent per annum respectively. Demand accelerates slightly in the United States after 2010, while it remains steady throughout the whole period in Europe. However, these similar growth rates mask a different evolution in the underlying drivers. In Europe, growth is driven by the vehicle stock (1.6 percent per annum), partly offset by strong fuel-economy improvements (minus 0.8 percent per annum), and with VMT almost stable (0.1 percent per annum). By contrast, growth in the United States comes from both vehicle stock and VMT (0.9 percent and 0.7 percent per annum respectively), with more moderate fuel-economy improvements of minus 0.5 percent per annum.

In the $70-oil scenario, demand takes a greater hit in the United States than in Europe, especially in the near term (Exhibit 15). Over the period 2005–2010, demand actually decreases by 0.8 percent annually in the United States as the result of a sharp drop in VMT (minus 1.6 percent per annum), reflecting the fact that US consumers drive significantly less in response to higher gasoline prices. Although European consumers also display this short-term, behavioral response, it is less than half as large (minus 0.7 percent per annum) due to higher fuel taxes. As a result, fuel demand only decreases by 0.1 percent in Europe to 2010 (Exhibit 16).

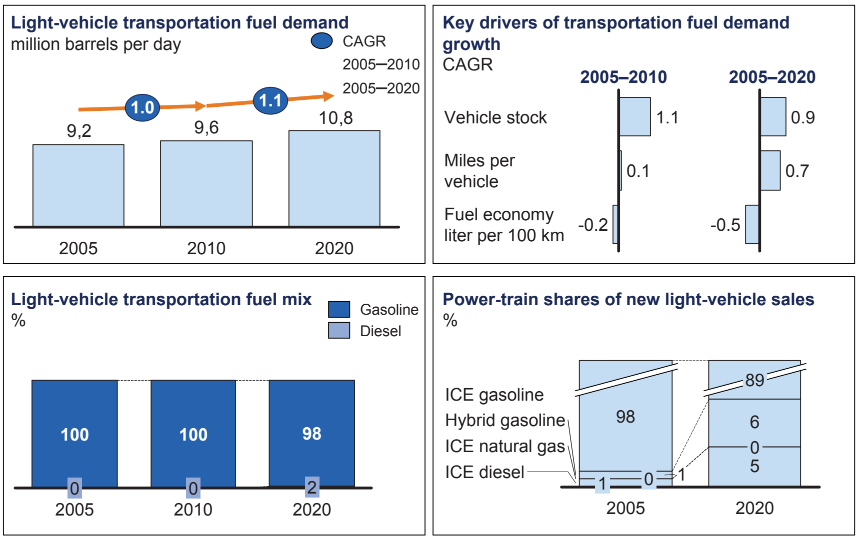
VMT alone does not explain this reduced growth to 2020 in the $70-oil scenario. In fact, the VMT drop will be neutralized in both regions by resumed VMT growth after 2010. Fuel-economy improvements follow the opposite path, since they accelerate mostly after 2010. In the United States, the rate of improvement to 2020 doubles to minus 1.0 percent per annum, while it increases to minus 1.3 percent per annum in Europe

7 The MGI model uses 2003 IEA data as a base year. However, thanks to the greater availability of data, actual 2005 consumption is used as a base year for both the US and Europe case studies.

## Exhibit 11

### UNITED STATES CASE STUDY – SYNTHESIS

$50-oil scenario

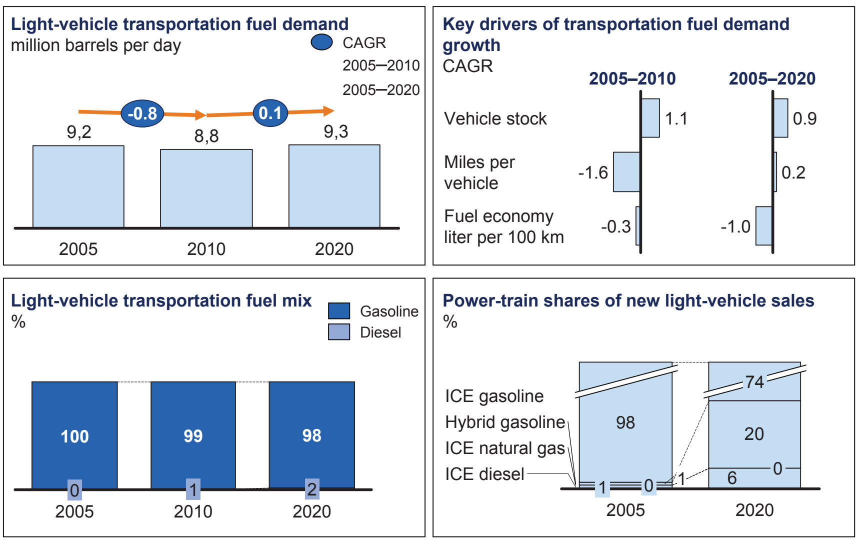



Source: IEA; Global Insight; MGI analysis

## Exhibit 12

### UNITED STATES CASE STUDY – SYNTHESIS

$70-oil scenario

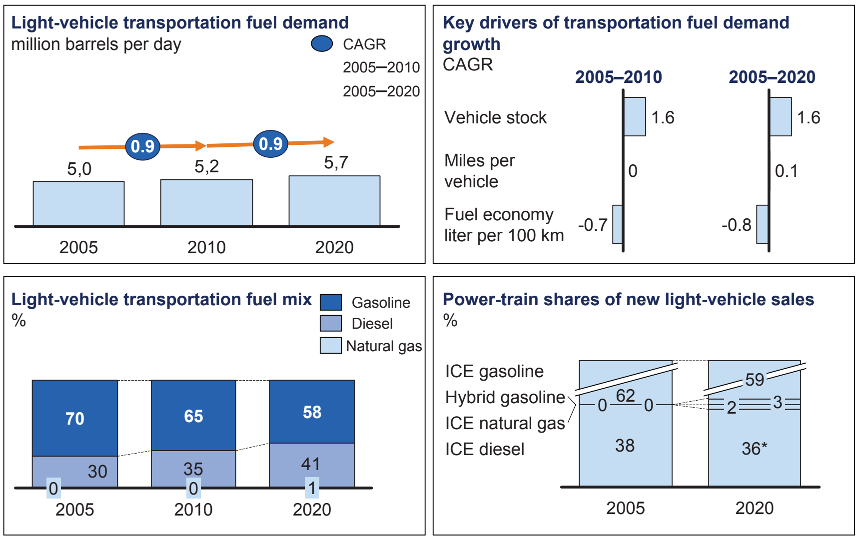



Source: IEA; Global Insight; MGI analysis

## Exhibit 13

### EUROPE CASE STUDY – SYNTHESIS

$50-oil scenario



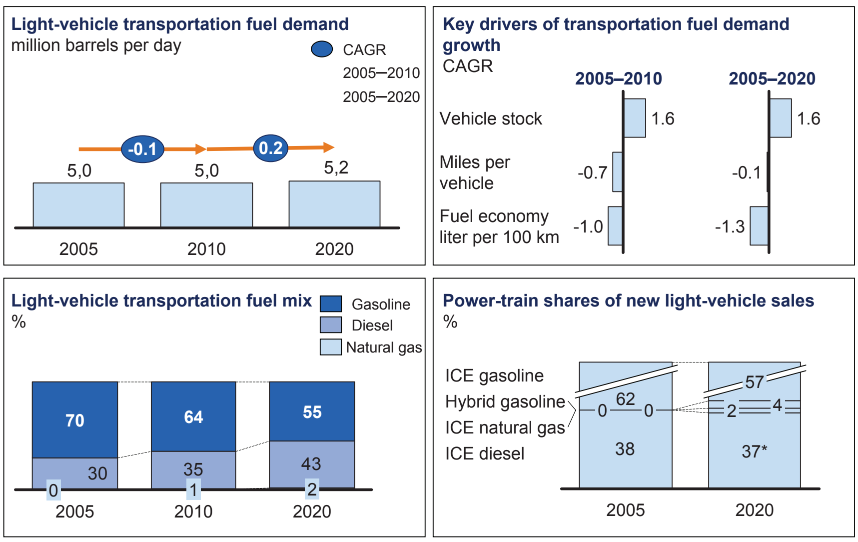

* 34% ICE diesel and 2% hybrid diesel.

Source: IEA; Global Insight; MGI analysis

## Exhibit 14

### EUROPE CASE STUDY – SYNTHESIS

$70-oil scenario




* 35% ICE diesel and 2% hybrid diesel.

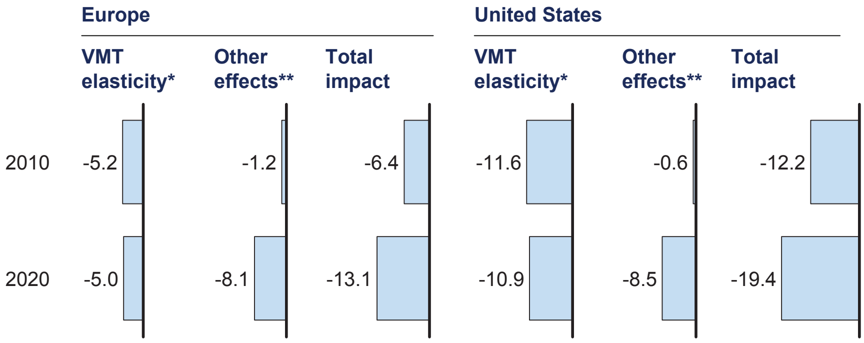
Source: IEA; Global Insight; MGI analysis

## Exhibit 15

### HIGH OIL PRICE REDUCES DEMAND GROWTH IN EUROPE AND THE UNITED STATES – SHORT TERM, THROUGH LOWER MILES DRIVEN; LONG TERM, THROUGH FUEL-ECONOMY IMPROVEMENTS

**Demand reduction between $30 oil-price scenario and $70 oil-price scenario**

%



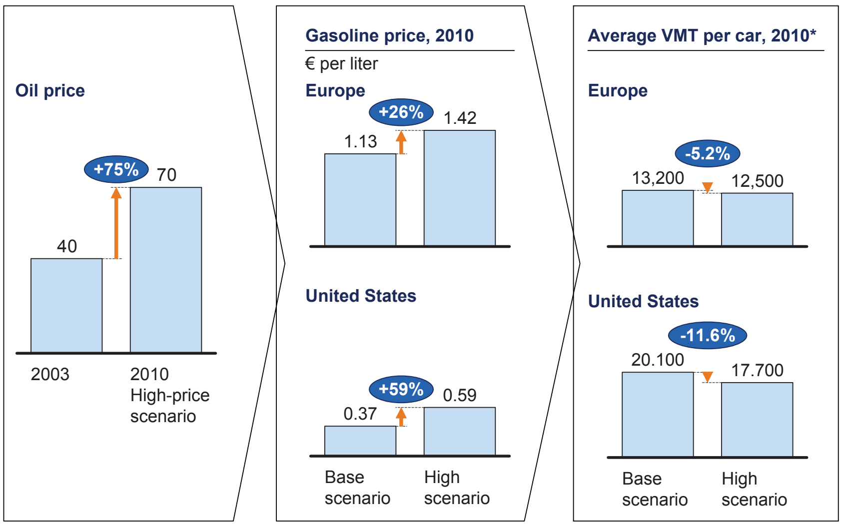

* Vehicle miles traveled.

** Other effects include fuel-economy improvements through engine enhancements, changes in the size/segment mix of new vehicles, and changes in the mix of power trains (diesel vs. gasoline, ICE vs. hybrid, etc.).

Source: McKinsey DRIVE model; MGI Global Energy Demand Model

## Exhibit 16

### HIGHER FUEL TAXES IN EUROPE DAMPEN RESPONSE TO HIGHER OIL PRICE FROM ELASTICITY OF MILES DRIVEN




* Assuming VMT elasticity of -0.2.

Source: McKinsey DRIVE model; MGI Global Energy Demand Model

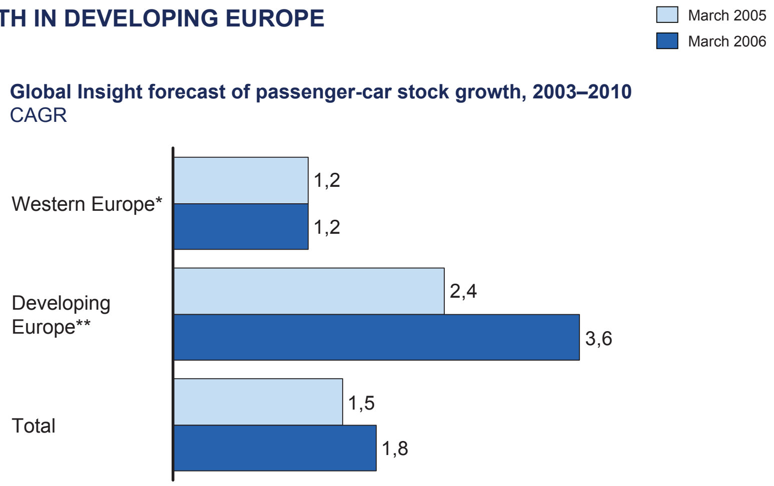
## Growth of the vehicle stock

The evolution of the light-vehicle stock reflects not only light-vehicle sales but also the average number of years for which these vehicles are kept on the road. To project the evolution of the stock, we therefore run light-vehicle sales forecasts by region through a "stock model" with detailed "scrappage rates" of vehicles by vintage year.[8]

Faster growth of the light-vehicle stock in Europe than in the United States mostly reflects its more rapid expansion of light-vehicle sales. Our projections, based on detailed Global Insight projections by country and by segment, show annual growth of sales of more than 3 percent in the broad "developing Europe" region covered in our case study, including new EU member states as well as Turkey and Russia (Exhibit 17). Furthermore, this trend is accelerating and, as a result, Global Insight recently revised up its forecast of light-vehicle stock growth in the region from 2.4 percent to 3.6 percent. Even in Western Europe, the light-vehicle stock grows slightly faster than in the United States at 1.2 percent per annum. By contrast, light-vehicle sales in the United States only grow around 0.5 percent annually to 2010.

**Exhibit 17**

**RECENT TRENDS POINT TO AN ACCELERATION OF VEHICLE-STOCK GROWTH IN DEVELOPING EUROPE**




* Including EU15 countries and Norway.
** Including Eastern Europe, Turkey, and Russia.
Source: Global Insight; MGI analysis

8 The "scrappage rate" expresses the percentage of vehicles that will be retired in a given year, which increases with the age of the vehicle. For this, we used both data from US National Transportation Statistics as well as estimates from academic literature.

These differences can be explained by the maturity of the light-vehicle market by country, measured by the penetration of personal vehicles per thousand inhabitants.[9] This ratio stands at 940 for the United States, well above the ratio for other developed countries—for example, the largest four EU countries all have a ratio of between 600 and 700 (620 in France; 640 in the United Kingdom; 650 in Germany; and 700 in Italy). Eastern European countries have even lower ratios, with Poland at 400 and Hungary at 350. The other two large countries in our case study—Russia and Turkey—have ratios of 200 and 100 respectively, demonstrating the scope for further sales growth in the future.

Another explanation for higher stock growth in Europe is that, in its segment mix, it has a lower share of light trucks (sport utility vehicles [SUVs] and pickups), which on average have a higher scrappage rate than passenger cars. This means that light-truck sales in the United States, which still represent half of the market, contribute less to growth of the stock than would equivalent car sales.

**Average miles traveled**

Beyond the impact of oil price on VMT, the United States and Europe also have different "business-as-usual" VMT-growth trends.

In Europe, miles driven have been stable for the last 15 years at around 13,000 km (slightly above 8,000 miles). Going forward, the only source of VMT growth in Europe will be a limited rebound effect occurring when consumers shift from gasoline to diesel cars, since diesel cars have a lower marginal driving cost thanks to better fuel economy, as well as to lower fuel taxes in most countries.

In the United States, VMT is still growing approximately 1 percent per annum. This figure is based on analysis of historical data, with a focus on periods of oil-price stability, such as in 1991–1999. This overall growth rate is largely driven by passenger cars (1.3 percent), with growth below 0.5 percent for light trucks.

**Current average fuel economy of the light-vehicle stock**

Before looking at projections of light-vehicle fuel economy, it is essential to understand the current situation. Average fuel economy, measured in liters per 100 km, is 37 percent worse in the United States than in Europe, which means that, for the same number of miles driven, fuel consumption is 37 percent higher in the United States (Exhibit 18).[10] Three factors explain this gap:

9 J.D. Power, LMC Automotive Forecasting Services.

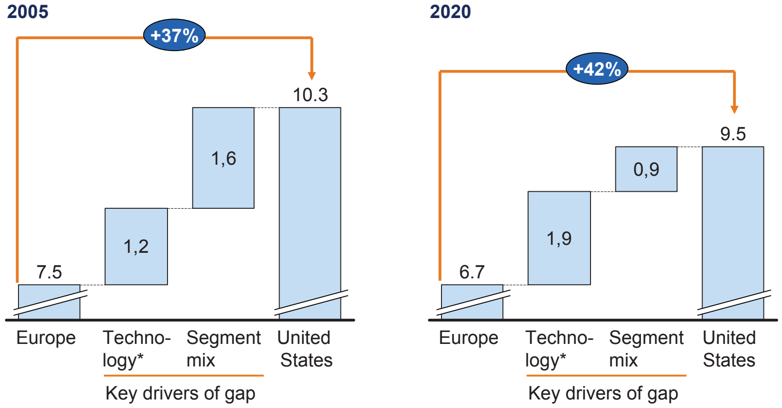
10 Measuring fuel economy in liters per 100 km (or gallons per mile) rather than miles per gallon has the advantage of relating directly to fuel consumption.

## Exhibit 18

**LOWER FUEL ECONOMY OF THE US LIGHT-VEHICLE STOCK LEADS TO 37 PERCENT EXTRA DEMAND VS. EUROPE FOR THE SAME MILES DRIVEN – A GAP INCREASING TO 42 PERCENT IN 2020**

**Average fuel economy of the light-vehicle stock**

Liters per 100 km, gasoline equivalent




* Includes the difference in fuel economy by power train (ICE gasoline in Europe vs. United States) and the mix of power trains (share of higher-efficiency ICE diesel in Europe vs. United States).

Source: MGI analysis

- Fuel economy by power train (e.g., the fuel economy of a standard gasoline internal-combustion-engine car);
- Mix of power trains (e.g., the share of more-efficient diesel cars in the stock);
- Segment mix (e.g., the share of less-efficient SUVs in the stock).

In 2005, the larger average vehicle size in the United States, driven by the high share of light trucks in the US light-vehicle stock, accounted for 55 percent of the gap, with the other two effects explaining the remaining 45 percent.

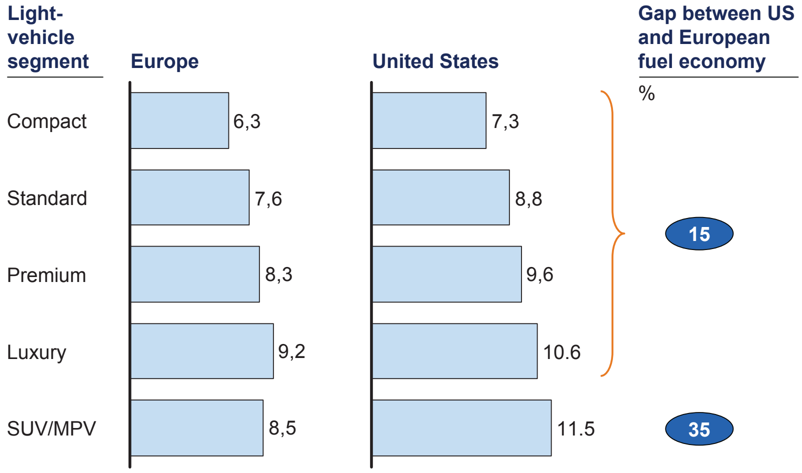
The comparison of 2005 fuel economy for a new gasoline internal-combustion-engine (ICE-gasoline) vehicle helps paint a picture of the “pure-technology” and segment-mix effects in greater detail (Exhibit 19). A new standard car in the United States consumes 8.8 liters of gasoline per 100 km driven (26.7 miles per gallon), 15 percent more than the equivalent car in Europe at 7.6l per 100 km (31.0 mpg). This ratio increases to 35 percent for the SUV/multipurpose vehicle (MPV) category. In other words, larger vehicles in the United States are much bigger than those in Europe—one explanation being that they are mostly based on truck technology rather than on car platforms as in Europe.

## Exhibit 19

### LIGHT VEHICLES SOLD IN EUROPE TODAY ARE MORE FUEL EFFICIENT THAN IN THE UNITED STATES

**2005 new vehicle fuel economy**

liters/100 km



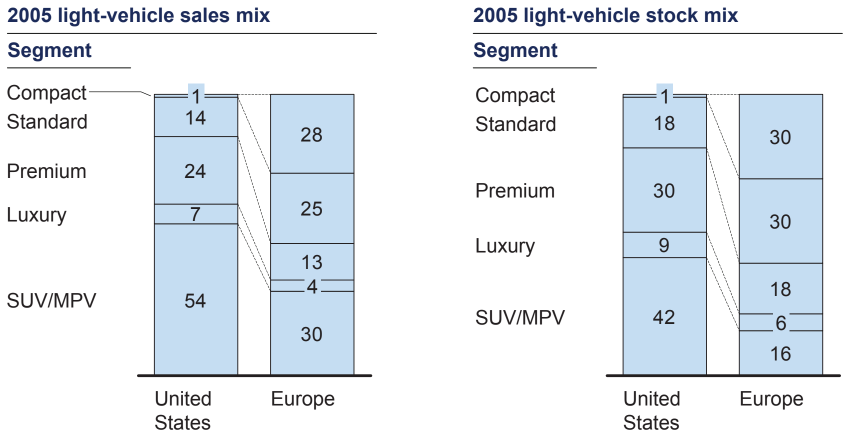

Source: Global Insight; McKinsey DRIVE model; MGI analysis

The importance of this 35 percent difference for the SUV/MPV category becomes clear when comparing this category's relative weight in the United States and Europe (Exhibit 20). In 2005, it represented 54 percent of light-vehicle sales in the United States, close to double its share in Europe. After a decade of strong sales, the category now accounts for 42 percent of the US light-vehicle stock, close to three times as high a proportion as in Europe where the trend toward SUVs is both more moderate and more recent. At the other end of the spectrum, compact and standard cars represent only 15 percent of sales and 19 percent of the stock in the United States compared with 53 percent and 60 percent in Europe.

Historical analysis sheds light on the origin of this large fuel-economy gap. In the United States, fuel economy increased sharply from 1975 to 1988 after the introduction of CAFE standards (Exhibit 21). This was achieved largely through a reduction in the average weight of vehicles, with the substitution of lighter materials such as aluminum, plastic, and steel. However, once CAFE standards had been met, fuel economy stopped improving as auto manufacturers focused on offering consumers increased horsepower, acceleration performance, and vehicle comfort, with a resulting increase in vehicle weight. Analysis by the US Environment Protection Agency shows that fuel economy would have improved by 24 percent had vehicle weight and performance remained at their 1987 levels (Exhibit 22).

## Exhibit 20

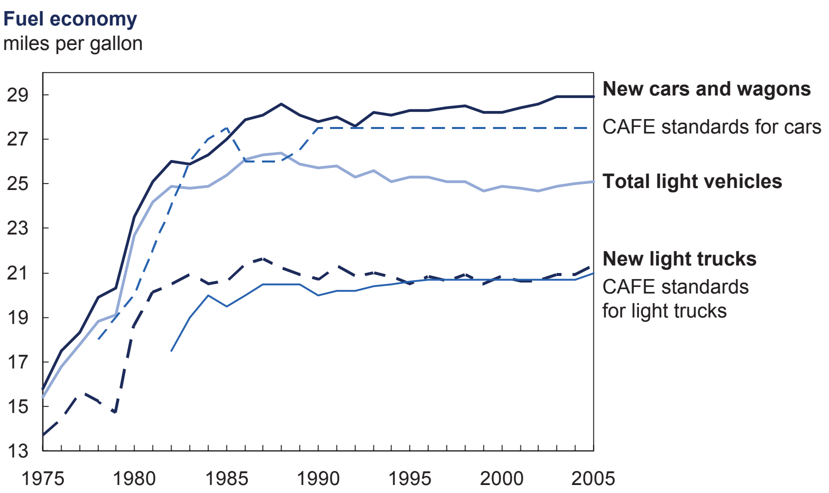
### THE EUROPEAN LIGHT-VEHICLE SIZE MIX ALREADY REFLECTS LONG-STANDING HIGHER FUEL PRICES
%




Source: Global Insight; McKinsey DRIVE model; MGI analysis

## Exhibit 21

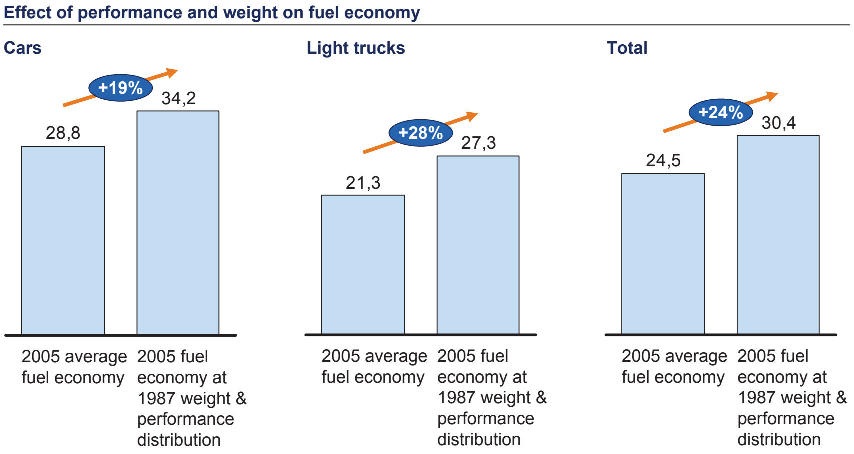
### AVERAGE FUEL ECONOMY OF US LIGHT VEHICLES ROSE SHARPLY IN 1975–1988 BUT STABILIZED ONCE CAFE STANDARDS WERE MET




Source: U.S. Environmental Protection Agency; MGI analysis

## Exhibit 22

**US FUEL ECONOMY WOULD HAVE IMPROVED BY 24 PERCENT IF VEHICLE WEIGHT AND PERFORMANCE HAD REMAINED AT 1987 LEVELS**




Source: U.S. Environmental Protection Agency analysis

Another important feature of CAFE standards is their separate requirements for cars and light trucks, the former much tighter than the latter at 27.5 miles per gallon instead of 20.7 miles per gallon. This double standard is the primary explanation for the higher fuel-economy gap for larger vehicles. Moreover, standards in the United States have remained constant since their introduction in 1975, whereas comparable standards, although voluntary, have been repeatedly tightened in Europe. Expressed in grams of $CO_2$ per km, current US standards are 205 grams for cars and 265 grams for light trucks, compared with 140 grams for all categories in Europe.

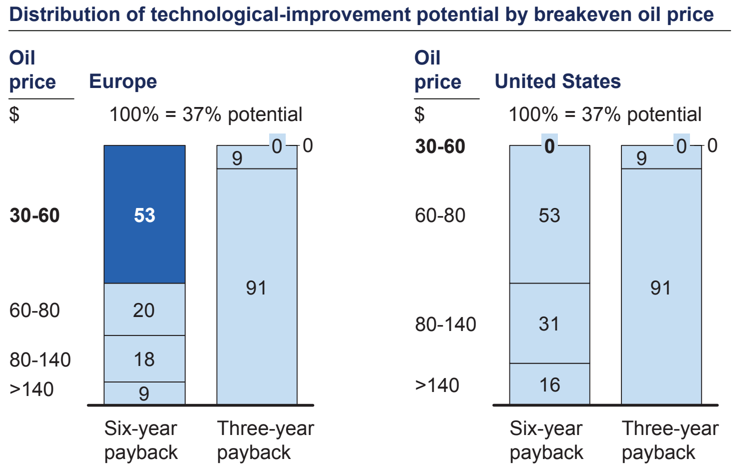
### Projected average fuel economy of the light-vehicle stock

We used the same three factors to project the evolution of average fuel economy. The overall outcome is a further widening of the fuel-economy gap between Europe and the United States from 37 percent today to 42 percent in 2020 (see Exhibit 18). The relative contribution of the underlying factors reverses strongly, with more, and faster, technology improvements in Europe accounting for two-thirds of the gap, and the segment-mix differential accounting for the remaining one-third (down from 55 percent previously).

Again, higher fuel taxes in Europe play a central role in creating incentives for consumers and auto manufacturers to adopt fuel-efficient technologies. Based on proprietary research by McKinsey's Global Automotive Practice,[11] we identified a comprehensive list of efficient technologies that are currently, or will soon be, available, with associated fuel savings and costs. We then determined the oil price at which each technology would break even from a consumer standpoint, by comparing the dollar value of fuel savings to the extra cost of the technology. The higher the retail fuel price, the lower the breakeven oil price. In Europe, more than half of the efficiency-improvement technologies would have a positive return with the oil price below $60 a barrel, against none in the United States (Exhibit 23).[12]

**Exhibit 23**

**HIGHER FUEL TAXES IN EUROPE MEAN THAT FUEL-SAVING TECHNOLOGIES BREAK EVEN AT A LOWER OIL PRICE THAN IN THE UNITED STATES**




Source: McKinsey DRIVE power-train model; MGI analysis

As a result, the fuel-economy gap for new vehicles will widen further between Europe and the United States by 2020. Taking the $70-oil scenario as an example—the most aggressive in terms of technologies introduced—the fuel economy of an ICE-gasoline vehicle increases by 27 percent in Europe compared with 19 percent in the United States, and 15 percent compared with 5 percent for an ICE-diesel vehicle (Exhibit 24). Moreover, technologies that do get introduced in the United States are, in general, introduced at least five years later than in Europe. This contributes to faster fuel-economy improvement in Europe, with a higher share of the 2020 stock equipped with efficient technologies (Exhibit 25).

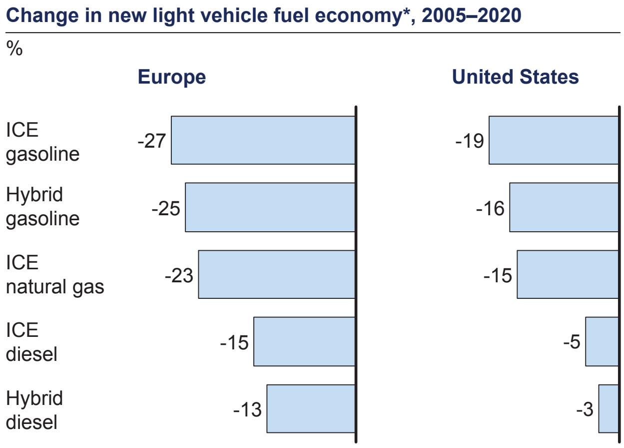
11 *DRIVE, The Future of Automotive Power*, McKinsey, 2006.

12 This assumes that consumers use a six-year horizon to value fuel savings, equivalent to a ten-year horizon with a 12 percent discount rate.

## Exhibit 24

### THE FUEL-ECONOMY GAP FOR NEW VEHICLES WILL WIDEN FURTHER BETWEEN EUROPE AND THE UNITED STATES BY 2020

$70-OIL SCENARIO

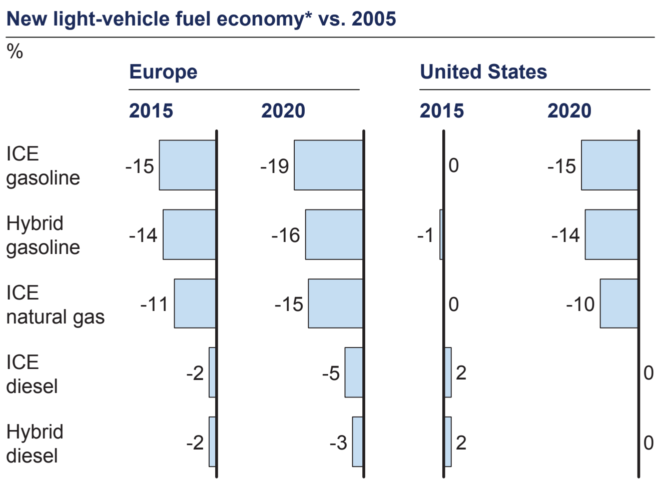



* Fuel economy expressed in liters per 100 km for standard-size vehicle.
Source: MGI analysis

## Exhibit 25

### FUEL-ECONOMY IMPROVEMENTS WILL BE INTRODUCED EARLIER IN EUROPE THAN IN THE UNITED STATES

$50-OIL SCENARIO



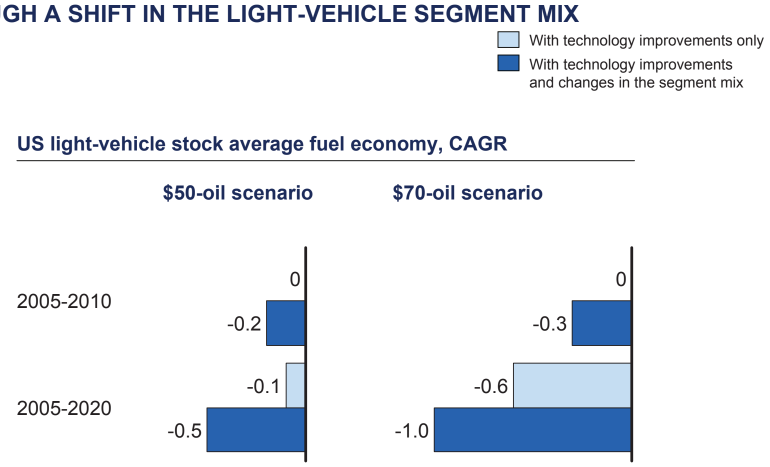

* Fuel economy expressed in liters per 100 km for standard-size vehicle.
Source: McKinsey DRIVE model; MGI analysis

In contrast, the mix of power trains has a limited impact on average fuel economy. In Europe, the penetration of diesel cars has reached a plateau and their share of total light-vehicle sales will remain comparable to today's level of slightly under 40 percent, even in a $70-oil scenario. This share hides large differences by country, with penetration already at or above 70 percent in countries like France but close to zero in countries like Russia or Turkey where diesel is not expected to take off. The United States will see a shift toward hybrid gasoline vehicles, whose market share could reach 20 percent in the $70-oil scenario. However, major penetration is not expected to take place before 2015, meaning that hybrids will only represent a small share of the 2020 vehicle stock. The same reasoning holds for diesel vehicles, currently unavailable in the United States. Improvements to ICE-gasoline vehicles, which currently represent 98 percent of the market, will have far more impact on average fuel economy.

Of the three drivers of fuel economy, only the segment-mix effect significantly plays out in favor of the United States. In fact, the segment-mix gap between the United States and Europe will almost halve by 2020 from 1.6 to 0.9 liters per 100 km. The shift toward smaller vehicles will contribute 100 percent of fuel-economy improvements to 2010 in the United States and a significant share of improvements to 2020: minus 0.4 percent out of minus 0.5 percent in the $50-oil scenario and out of minus 1.0 percent in the $70-oil scenario (Exhibit 26).

**Exhibit 26**

**FUEL ECONOMY WILL ALSO IMPROVE IN THE UNITED STATES THROUGH A SHIFT IN THE LIGHT-VEHICLE SEGMENT MIX**




Source: McKinsey DRIVE model; MGI analysis

This projection is based on an extrapolation of recent trends in US light-vehicle sales, which show a sharp fall in larger light trucks in favor of either car-based CUVs or cars (Exhibits 27). Cars will recapture a clear majority of the light-vehicle market before 2010 in both the $50- and $70-oil scenarios; by 2020 their share will reach 56 percent and 60 percent respectively. We also model a continuation of the shift toward CUVs that would capture a majority of light-truck sales by 2015 in the $70-oil scenario, leading to a significant fuel-economy gain for the light-truck segment (Exhibit 28). A recent KPMG survey of the global automotive industry confirms this, with a mere 3 percent of US executives surveyed expecting to see growth in the SUV sector in 2007, against 55 percent of respondents expecting market-share growth in the crossover segment.[13]

## CHINA ROAD-TRANSPORTATION CASE STUDY

China's road-transportation fuel demand experiences rapid growth to 2020 across all oil-price scenarios, ranging from 5.8 percent per annum in the $70-oil scenario to 6.6 percent per annum in the $30-oil scenario. Growth is fastest until 2010—at 7.7 percent in the base $50-oil scenario—and then decelerates. It is entirely driven by extremely rapid growth in the vehicle stock of 10.7 percent per annum to 2010 and 9.4 percent a year to 2020. Depending on the scenario, vehicle miles driven decrease between 2 percent and 3 percent per annum because of combined income and fuel-price effects, while recently introduced fuel-economy standards ensure significant fuel-economy improvements of between minus 0.7 percent and minus 0.9 percent per annum. The synthesis of our China case study is presented in Exhibits 29 and 30.

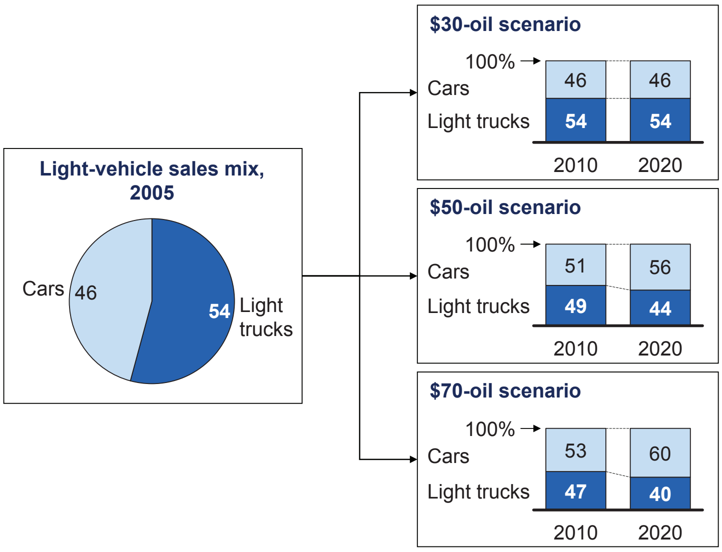
### Growth of the vehicle stock

Increased vehicle penetration in China is by far the single most important driver of road-transportation fuel demand. In recent years, China has clearly entered the steeper part of the "S-curve" of vehicle penetration, and looks set to continue on this trajectory of fast growth in coming years. Since 2000, several segments of the Chinese vehicle market have grown exponentially—the compact- and standard-car segments have grown by 30 percent a year compared with 12 percent in 1995–2000 (Exhibit 31). The premium and luxury segment, already growing at 20 percent annually before 2000, has soared by 37 percent a year since. Overall, the vehicle-market growth rate has almost tripled, from 8 percent to 23 percent annually.

13 *Momentum, KPMG Global Auto Executive Survey*, 2007, (www.kpmg.com/Industries/IM/Other/AutoExec2007.htm).

## Exhibit 27

### WE PROJECT THE IMPACT OF OIL PRICE ON THE US VEHICLE MIX OF CARS AND LIGHT TRUCKS...



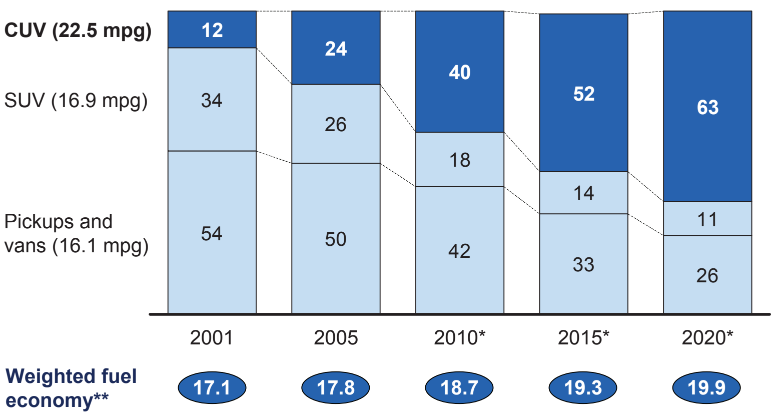

Source: MGI analysis

## Exhibit 28

### ... AND THE IMPACT ON THE LIGHT-TRUCK SALES MIX, WITH A SIGNIFICANT IMPACT ON AVERAGE FUEL ECONOMY

$70-OIL SCENARIO

**Mix and average fuel economy of US light-truck sales, 2001–2020**

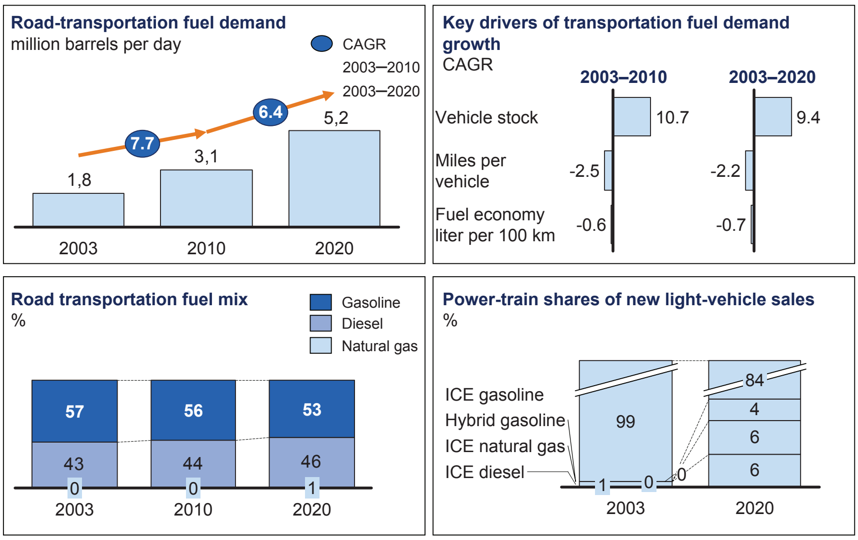



* MGI model assumptions based on historical growth rates.
** Assuming constant fuel economy by light truck category.
Source: Ward's AutoInfoBank; MGI analysis

## Exhibit 29

### CHINA CASE STUDY – SYNTHESIS

$50-oil scenario

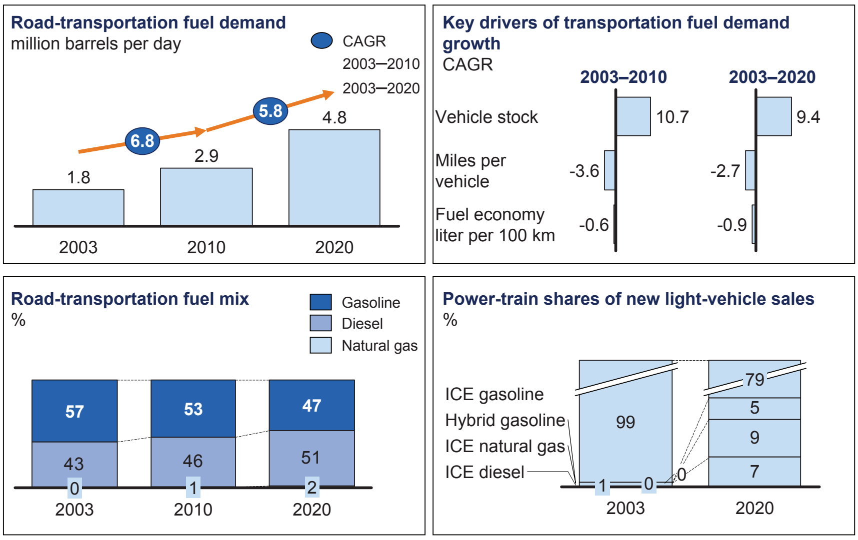



Source: IEA; Global Insight; MGI analysis

## Exhibit 30

### CHINA CASE STUDY – SYNTHESIS

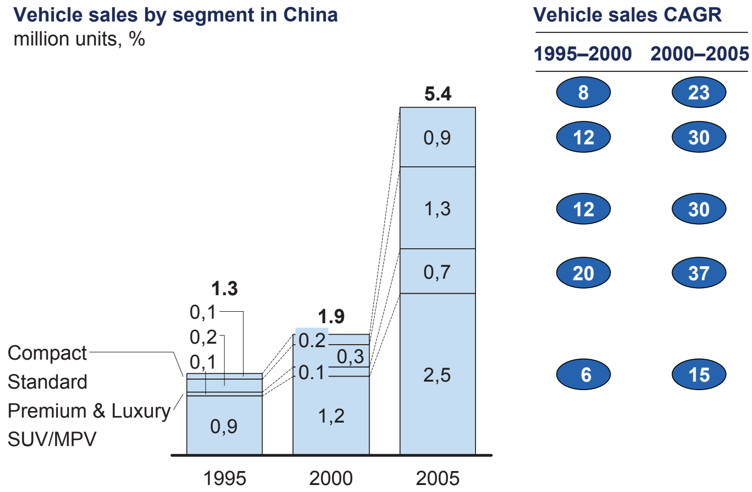
$70-oil scenario




Source: IEA; Global Insight; MGI analysis

**Exhibit 31**

**SINCE 2000, CHINA HAS ENTERED A PHASE OF EXPONENTIAL VEHICLE-SALES GROWTH**



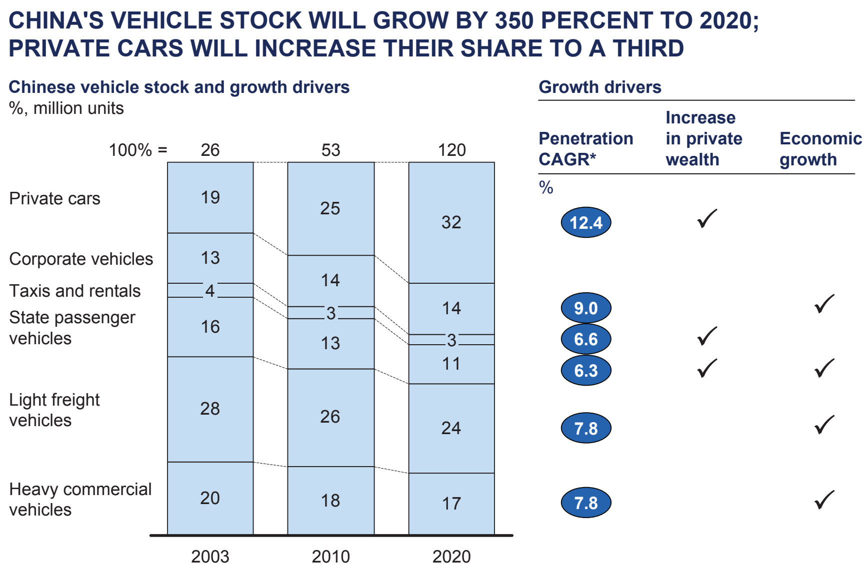

Source: Global Insight; MGI analysis

Going forward, China's total vehicle stock is projected to grow by 350 percent to 2020 in our base case, from 26 million in 2003 to 120 million in 2020. In terms of segments, the increase is strongest for private cars, whose share increases to one-third of the total stock, up from one-fifth today. The stock grows by 9 percent per annum for corporate vehicles and close to 8 percent for both light- and heavy-freight vehicles (Exhibit 32). These numbers reflect the projected strong growth of private urban consumption by China's rising middle class, a phenomenon that MGI has researched extensively.[14]

The growth of the vehicle stock is driven by increased penetration—overall, the number of vehicles per thousand inhabitants increases from 20 in 2003 to 85 in 2020. The mix of freight and personal vehicles also changes, with the share of freight decreasing from 50 percent to 40 percent. We determine vehicle penetration based on income elasticity by vehicle category combined with vehicle-price elasticity. Vehicle prices have been declining in recent years in China, making vehicle ownership affordable for a larger share of the emerging middle class, for which it represents not only a means of transportation but also a status symbol.

14 *From 'Made in China' to 'Sold in China': The Rise of the Chinese Urban Consumer*, McKinsey Global Institute, November 2006, (www.mckinsey.com/mgi/publications/china_consumer/index.asp).

**Exhibit 32**




* Penetration CAGR = GDP CAGR x vehicle-type income-growth elasticity adjusted for vehicle-price elasticity.
Source: Global Insight; Fourin Report – China's Taxi Market; China Info Bank; expert interviews; MGI analysis

A number of other indicators confirm that car penetration will boom in China. For instance, the country now has a higher ratio of car dealerships per square mile than the United States. The number of potential clients for these dealerships, i.e., licensed drivers, more than doubled in 1999–2004. The annual road-construction budget in China also doubled in 2000–2004 (Exhibit 33).

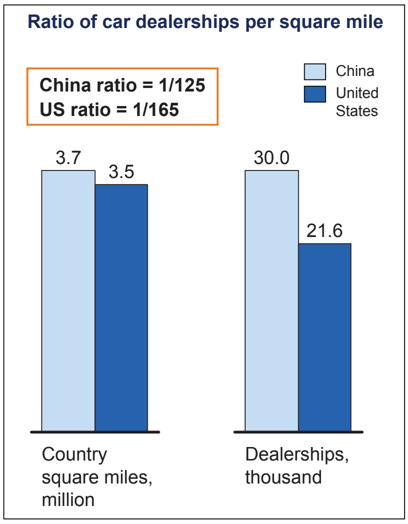
### Average miles traveled

"Business-as-usual" VMT in China actually declines by 2.2 percent per annum to 2020, reflecting a continuation of the historical growth trend, albeit at a more moderate pace—average VMT has been declining at an average 4.3 percent per annum since 1990, but fell by only 2.8 percent in 2005. This is due to the fact that consumers generally drive their cars less as an economy develops, with usage shifting from quasi-commercial and shared toward more leisure and personal-comfort travel.

With fuel prices fully exposed to oil-price fluctuations, China sees a slightly lower VMT impact than the one we expect in the United States. VMT will decrease by an additional 1.0 percent per annum between 2003 and 2010 in the $70-oil scenario compared with the $30-oil scenario (Exhibit 34).

## Exhibit 33

### SEVERAL INDICATORS CONFIRM THAT CHINA'S CAR-PENETRATION BOOM WILL CONTINUE

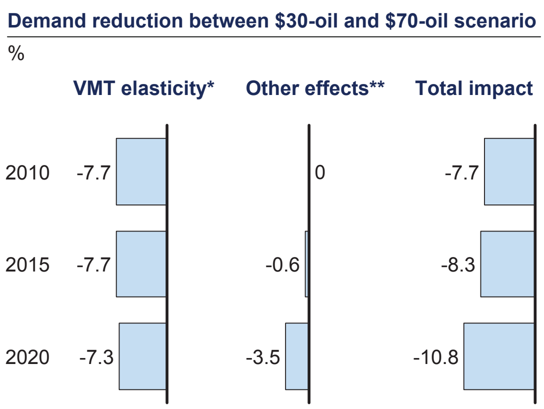




Source: Global Insight; press search; MGI analysis

## Exhibit 34

### IN CHINA, MOST OF THE DEMAND REDUCTION WILL COME FROM FEWER MILES DRIVEN




* Vehicle miles traveled.

** Other effects include fuel-economy improvements through engine enhancements, changes in the size/segment mix of new vehicles, and changes in the mix of power trains (ICE, diesel, hybrids, etc.).

Source: McKinsey DRIVE model; MGI analysis

### Average fuel economy of the light-vehicle stock

The recent introduction of national, weight-based fuel-economy standards will favor the introduction of fuel-efficient technologies. The fact that these standards are taking effect as China enters a phase of extremely rapid vehicle-stock growth means that they will deliver impact there faster than they will in developed regions with mature vehicle markets such as the United States.

China will also see a diversification of its power-train mix toward higher-efficiency power trains, with ICE diesel, ICE natural gas, and hybrid gasoline representing a balanced 16 percent market share in the $50-oil scenario. In the $70-oil scenario, this share would increase to 21 percent to the benefit of natural gas (9 percent) and diesel (7 percent).

Together, these effects will lead to significant fuel-economy improvements in China in the period to 2020 of minus 0.7 percent per annum in the $50-oil scenario and minus 0.9 percent per annum at $70-oil.

## IV. KEY UNCERTAINTIES AROUND THE MGI BASE-CASE SCENARIO

As described in the previous section, both GDP growth and the oil price impact road-transportation fuel-demand growth. By combining our three scenarios around each of these variables, annual demand growth could swing between 1.2 percent in a low-GDP-growth, $70-oil environment, and 2.9 percent in a high-GDP-growth, $30-oil environment (Exhibit 35). This would represent a range of uncertainty of 26 QBTUs around our base-case demand scenario by 2020, equivalent to 13.5 million barrels per day of road transportation fuel.

### GDP uncertainty

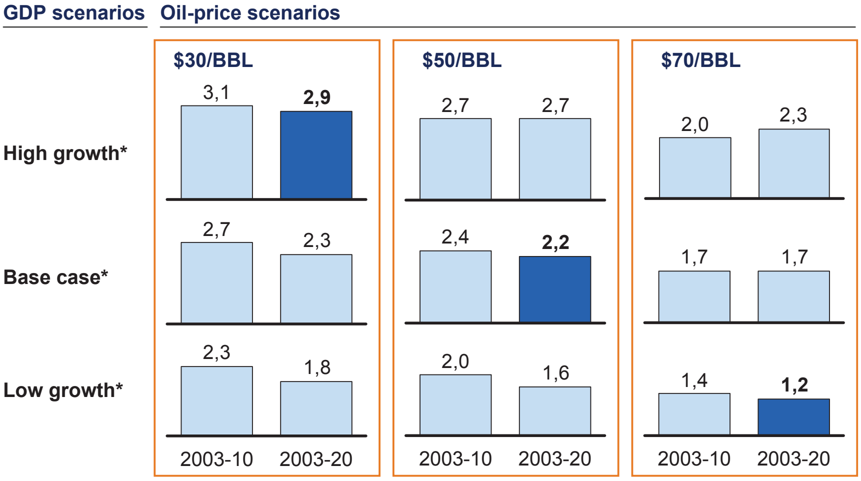
Potential changes in projected GDP growth could drive annual-demand growth down to 1.6 percent (an 8 QBTU reduction versus the base-case scenario) or up to 2.7 percent (a 10 QBTU increase). Our GDP scenarios assume variations compared with our base case of plus or minus 2 percent for China and India where GDP projections carry the most uncertainty, plus or minus 1 percent for other developing regions, and plus or minus 0.5 percent for developed regions.

Breaking down variability by region, China is the single largest driver of uncertainty with a 6.6 QBTU swing between the low- and high-GDP scenarios, representing close to 40 percent of the global uncertainty. The Middle East also contributes a large share due to its high multiplier between GDP and fuel-demand growth. Together, the Middle East and China represent more than half of the overall uncertainty we estimate. By contrast, the United States and Europe represent slightly less than 25 percent (Exhibit 36).

## Exhibit 35

### ANNUAL ENERGY DEMAND GROWTH COULD SWING BETWEEN 1.2 AND 2.9 PERCENT DEPENDING ON GDP GROWTH AND OIL-PRICE SCENARIOS

Annual growth, %

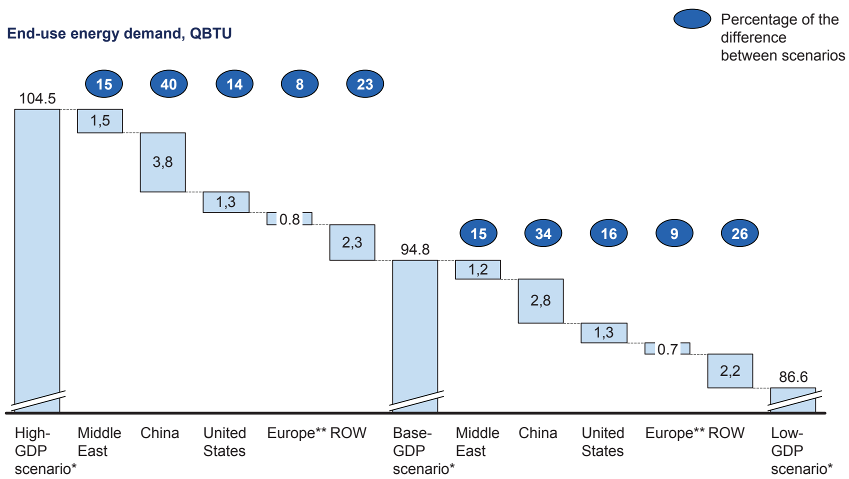



* Base-case growth of 3.2% globally; variations of ±2% for China and India, ±1% for other developing regions, and ±0.5% for developed economies.

Source: MGI Global Energy Demand Model

## Exhibit 36

### UNCERTAINTY AROUND GDP GROWTH STANDS AT 18 QBTUS, OF WHICH HALF COMES FROM CHINA AND THE UNITED STATES




* Base-case growth of 3.2% globally; variations of ±2% for China and India, ±1% for other developing regions, and ±0.5% for developed economies.

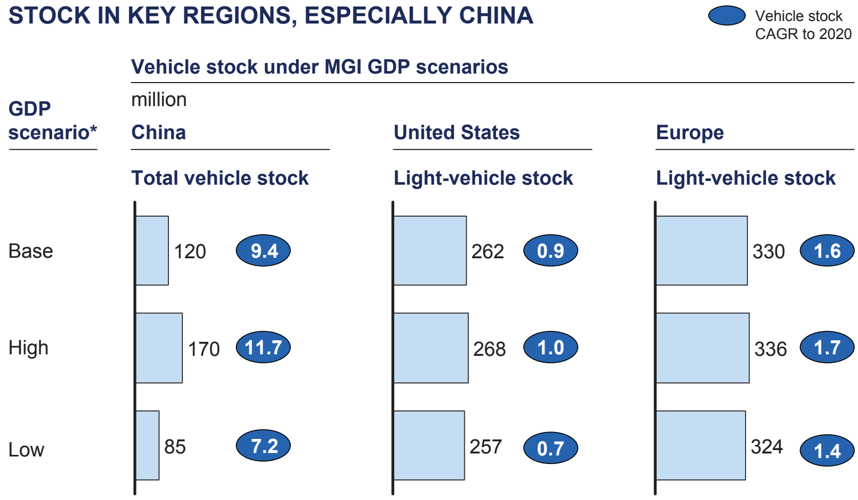
** Including Northwestern Europe, Mediterranean and North Africa, and Baltic/Eastern Europe.

Source: MGI Global Energy Demand Model

These differences in demand growth rates by region can be explained by the impact of GDP on vehicle stock (Exhibit 37). For light vehicles in the United States and Europe, this effect is modeled through a GDP elasticity of light-vehicle sales: 1 percent of extra GDP growth increases sales by 0.75 percent in Europe and by 0.8 percent in the United States.[15] This difference in sales is, in turn, reflected in growth of the total light-vehicle stock: 1.7 percent and 1.0 percent for Europe and the United States respectively in the high-GDP scenario, and only 1.4 percent and 0.7 percent respectively in the low-GDP scenario. For China, this effect is modeled through changes in vehicle penetration, with growth of vehicles per thousand inhabitants proportional to GDP growth. As a result, the 2020 vehicle stock in China in the high-GDP scenario could be twice as high as in the low-GDP scenario, with 170 million vehicles instead of 85 million.

**Exhibit 37**

**THIS UNCERTAINTY IS DRIVEN BY THE IMPACT OF GDP ON VEHICLE STOCK IN KEY REGIONS, ESPECIALLY CHINA**




* Base-case growth of 3.2% globally; variations of ±2% for China and India, ±1% for other developing regions, and ±0.5% for developed economies.

Source: MGI analysis

### Oil-price uncertainty

*Impact of oil price on demand growth and consumer fuel mix*

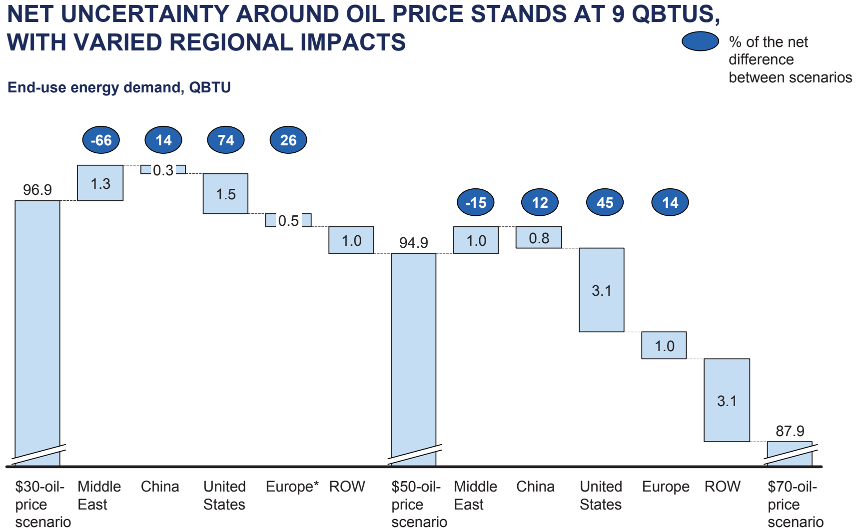
At 9 QBTUs, global uncertainty around oil-price scenarios is only half the size of that around GDP scenarios. In a $70-oil scenario, global fuel demand grows at 1.7 percent per annum (a 7 QBTU reduction) versus 2.3 percent in a $30-oil

15 G. K. Ingram and Z. Liu, *Determinants of Motorization and Road Provision*, Research Advisory Staff and the Transport, Water, and Urban Development Department; J. Dargay and D. Gately, *Income's effect on car and vehicle ownership worldwide: 1960-2015*, New York University, 1997; expert interviews.

scenario (a 2 QBTU increase). However, this global response conceals the true magnitude of the oil-price impact by region, especially since demand increases in oil-exporting regions when the oil price increases (Exhibit 38).

**Exhibit 38**

**NET UNCERTAINTY AROUND OIL PRICE STANDS AT 9 QBTUS, WITH VARIED REGIONAL IMPACTS**



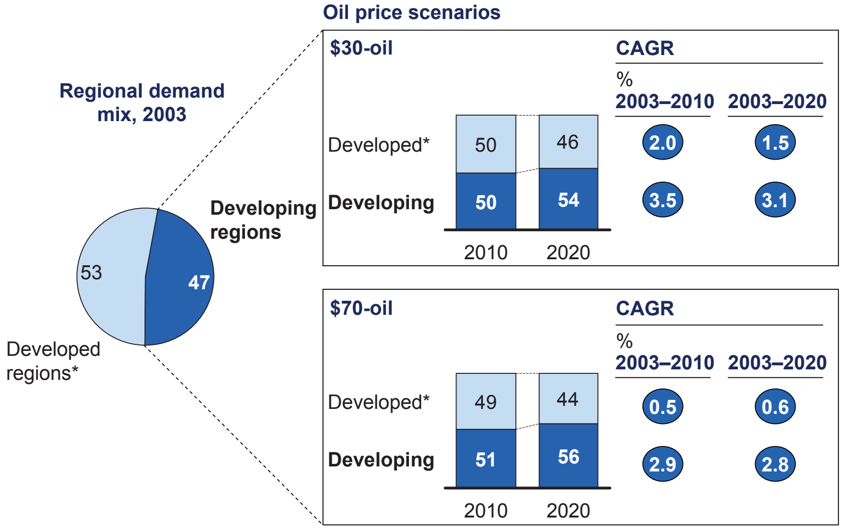

* Including Northwestern Europe, Mediterranean and North Africa, and Baltic/Eastern Europe.
Source: MGI Global Energy Demand Model

The different forms of demand elasticity at work in the MGI oil-price scenarios impact both the geographic breakdown and the fuel mix of road-transportation energy demand.

Most of the demand reduction in the $70 oil-price scenarios takes place in developed regions. As a result, developing regions represent a higher share of global demand in the $70-oil scenario (Exhibit 39). Demand growth to 2020 in developed regions more than halves from 1.5 percent per annum in the $30-oil scenario to 0.6 percent in the $70-oil scenario. At the same time, demand in developing regions remains relatively stable at 2.8 percent instead of 3.1 percent. This stability is due to counterbalancing demand increases in oil-exporting regions such as the Middle East or Venezuela and decreases in oil-importing regions. Consequently, the Middle East—the region with by far the largest subsidies—sees its share of total demand in developing regions increase by close to 50 percent in the $70-oil scenario. China's share, on the other hand, remains similar due to the limited impact of the oil price on its strongly growing demand. Across all scenarios, China's share of developing regions' demand almost doubles to around 20 percent by 2020 (Exhibit 40).

## Exhibit 39

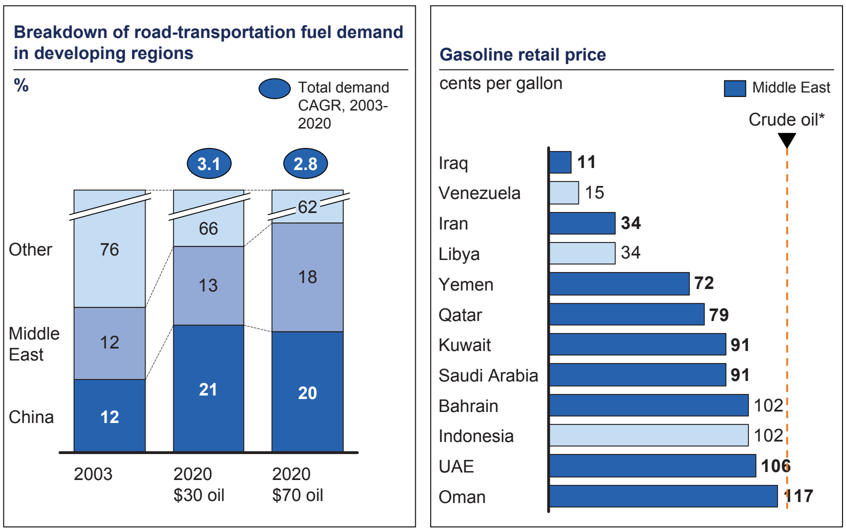
### IN THE $70-OIL SCENARIO THE ROAD-TRANSPORTATION DEMAND MIX SHIFTS FURTHER TOWARD DEVELOPING REGIONS...




* United States, Canada, Northwestern Europe, Japan.
Source: IEA; MGI Global Energy Demand Model

## Exhibit 40

### ... AND IN PARTICULAR TOWARD THE MIDDLE EAST WHERE HIGH SUBSIDIES INSULATE CONSUMERS FROM OIL PRICE

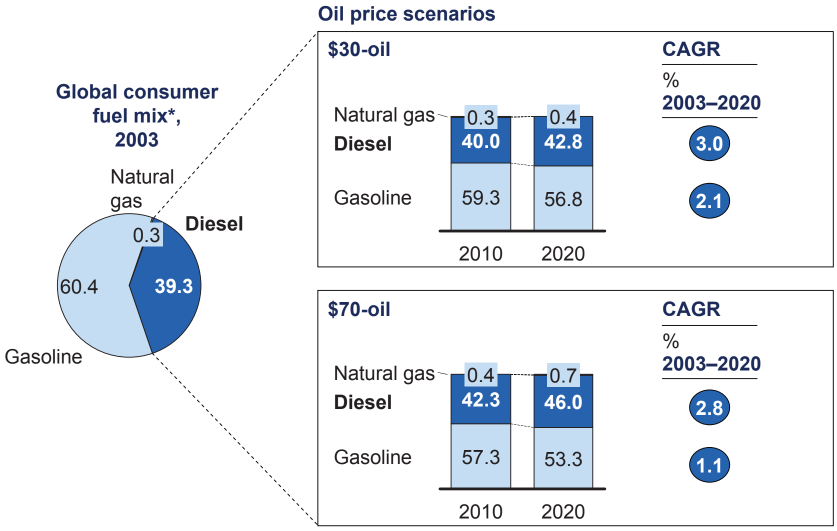



* $50 crude oil equals 119 cents per gallon.
Source: GTZ, International Fuel Prices 2005; MGI analysis

In terms of consumer fuel mix, high oil prices accelerate the shift toward diesel, which gains more than 6 percent of global market share over gasoline in the $70-oil scenario (from 39.3 percent in 2003 to 46.0 percent in 2020), more than twice the gain in the $30-oil scenario (Exhibit 41). This extra gain comes from the lower elasticity of diesel demand: in the same way that most of the demand reduction occurs in developed regions in the $70-oil scenario, most of the reduction comes from gasoline, with growth falling from 2.1 percent to 1.1 percent, while diesel-demand growth remains close to 3 percent per annum. There are three main reasons for this lower elasticity of diesel demand. First, diesel is by far the predominant fuel used in freight transportation, where price elasticity is lower. Second, a higher share of global diesel demand is subsidized (Exhibit 42). Third, diesel also gains share in the passenger-transportation mix due to its higher fuel economy. This trend is clear at the regional level, especially in Northwestern Europe where gasoline demand would actually decrease by 2020 as the result of these combined effects (Exhibit 43). In all cases, natural gas, although experiencing fast growth in the $70-oil scenario, remains marginal, accounting for less than 1 percent of global demand.

**Exhibit 41**

**HIGH OIL PRICES ALSO ACCELERATE THE SHIFT TOWARD DIESEL**




* In this report, fuel mix reflects consumers' choices between gasoline and diesel vehicles. It does not include any assumptions regarding actual blending of motor fuels with ethanol or biodiesel.

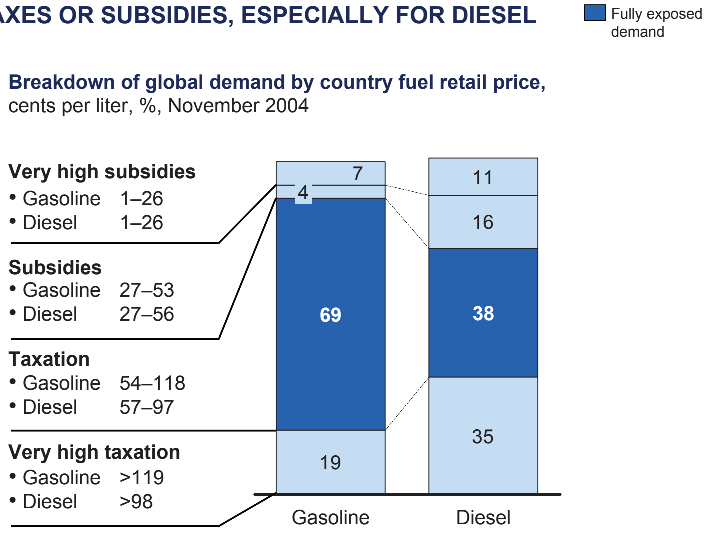
Source: IEA; MGI Global Energy Demand Model

*Underlying mechanisms*

In the United States and Europe, high oil prices reduce fuel-demand growth through a combination of short- and long-term effects, especially for light vehicles. In the short term, consumers adjust to higher fuel prices by driving less—for example,

## Exhibit 42

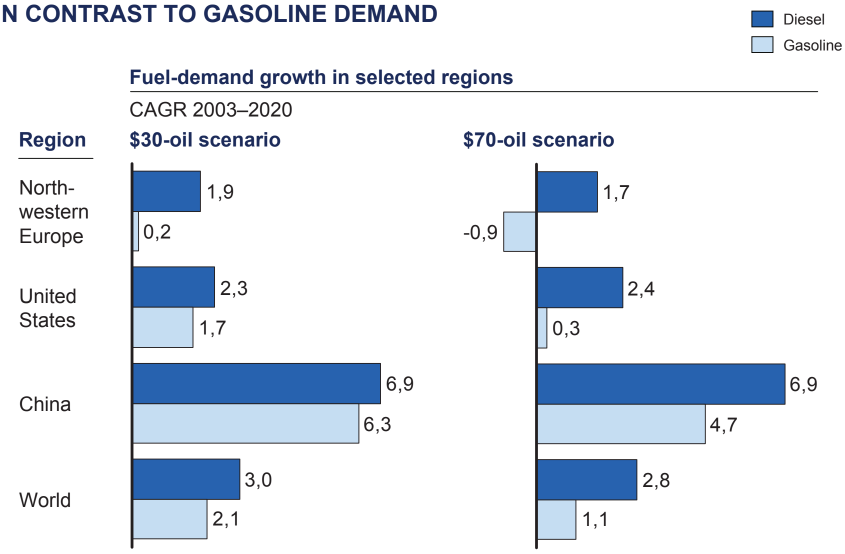
### A LARGE SHARE OF GLOBAL FUEL DEMAND IS INSULATED FROM OIL PRICE BY TAXES OR SUBSIDIES, ESPECIALLY FOR DIESEL




Source: GTZ International Fuel prices 2005; MGI analysis

## Exhibit 43

### DIESEL DEMAND GROWS STRONGLY ACROSS OIL-PRICE SCENARIOS, IN CONTRAST TO GASOLINE DEMAND




Source: IEA; MGI Global Energy Demand Model

by canceling nonessential trips, grouping trips, carpooling, or switching to public transportation. This effect is captured through a minus 0.2 price elasticity; that is, a 10 percent increase of retail fuel price leads to a 2 percent reduction in miles driven. Because of this effect, 2010 demand in the United States is 12 percent lower in the $70-oil scenario than in the $30-oil scenario. Europe sees a more limited reduction of 5 percent because of its higher fuel taxes. Mechanically, higher fuel taxes mean that a given oil-price increase translates into a lower percentage increase in the retail-fuel price. In practice, a rise in the oil price to $70 per barrel implies a 26 percent increase in the pump price in Europe, but a hike of 59 percent in the United States.

In the long term, consumers respond to higher fuel prices by choosing more fuel-efficient vehicles. The relative size of this effect is comparable for the United States and Europe, lowering demand by approximately 8 percent in the $70-oil scenario compared with the $30-oil scenario. Consumers get improved fuel economy either by shifting to smaller segments (a car instead of an SUV, or a smaller SUV) or simply by picking the most fuel-efficient vehicle within each segment. From the point of view of auto manufacturers, higher fuel prices thus create a double incentive to introduce fuel-saving technologies such as direct injection. First, higher retail fuel prices mean that more fuel-saving technologies break even from a purely economic consumer standpoint.[16] Higher fuel prices also give fuel economy greater weight as a qualitative purchase factor. For instance, in a recent survey of the global automotive industry, 89 percent of the senior 150 executives at auto manufacturers and suppliers interviewed felt that fuel efficiency would be an important purchase factor for consumers, ranking it as the single most important factor.[17]

However, the overall demand response in Europe and the United States is in fact more moderate than what our light-vehicle case studies suggest, since price elasticity in freight transportation is significantly lower.

In China, most of the demand reduction would come from lower miles driven. Like the United States, China currently has moderate fuel taxes (as opposed to subsidies until 2005), leading to an 8 percent short-term demand response in the $70-oil scenario. However, the long-term response through improved fuel economy is less than half as large in China than in Europe or the United States, for two reasons. First, the current mix of cars, with higher share of compact

16 Breakeven point is defined here as the difference between the extra cost to the consumer of the fuel-saving technology and the monetary value of the associated fuel savings.

17 *Momentum, KPMG Global Auto Executive Survey*, 2007, (www.kpmg.com/Industries/IM/Other/AutoExec2007.htm).

cars, is already more fuel efficient. Second, China has recently introduced fuel-economy standards that will already capture a high proportion of "low-hanging fruit" in terms of fuel-economy improvements, regardless of the oil-price scenario. As a result, the country represents only a modest share of the global uncertainty around the oil price.

In oil-exporting regions, fuel demand actually increases along with the oil price: Middle East fuel demand growth to 2020, for example, increases from 4.6 percent to 5.3 percent per annum between the $50-oil and $70-oil scenarios. Two mechanisms underlie this: oil revenues boost GDP growth and subsidies maintain low fuel prices for consumers.

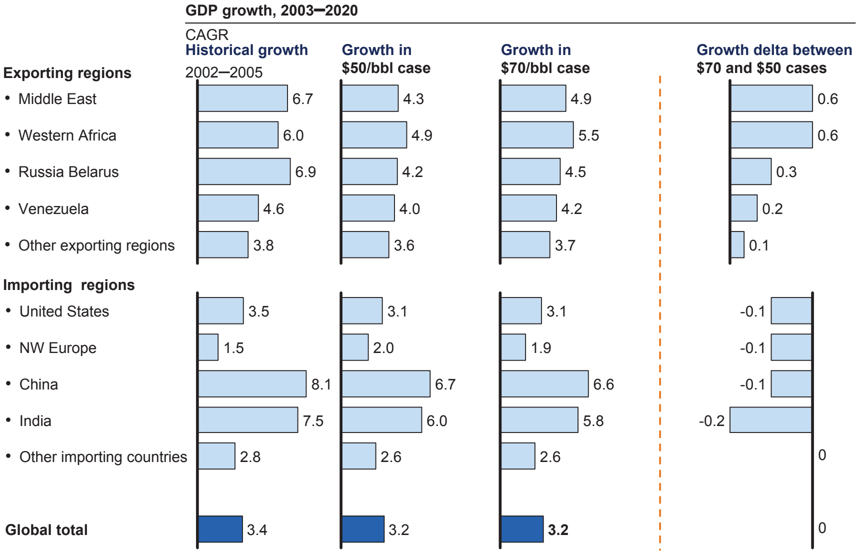
We model a sizeable positive elasticity of GDP growth to oil-price change in oil-exporting regions. GDP growth in the Middle East, which stands at 4.3 percent per annum in the $50-oil scenario, increases to 4.9 percent at $70 per barrel (Exhibit 44). This effect is further compounded by the fact that GDP growth in these regions tends to be much more energy-intensive than in oil-importing countries, in great part because of high fuel subsidies. In 2004, the average price per gallon of gas was only around 16 cents in Venezuela and 12 cents in Iraq. Even with some countries subsidizing less, the highest price of transportation fuels in the Middle East is currently around $1 a gallon, well below the market price. As oil prices increased, these subsidies remained in place, and demand grew strongly. Light-distillate demand in the Middle East grew by 7.8 percent in 2004 and by 6.6 percent in 2005, representing more than 50 percent of global demand growth that year (Exhibit 45).

## MARKET HAS SLOW INITIAL REACTION TO HIGH OIL PRICES

Since 2003, MGI scenarios' baseline year for demand, the oil price has more than doubled—the spot price per barrel of Brent rose from an average of $29 in 2003 to $38 in 2004, $55 in 2005, and $65 in 2006. Based on MGI case studies, we expect to see significant demand-growth reduction in regions where fuel prices reflect oil-price changes, such as in the United States. Looking at actual demand data, road-transportation fuel demand has indeed started to respond to price, but with a significant time-lag due to the presence of shock absorbers. However, now that several of the shock absorbers have worn off, we expect demand to continue responding significantly if oil prices remain high.

## Exhibit 44

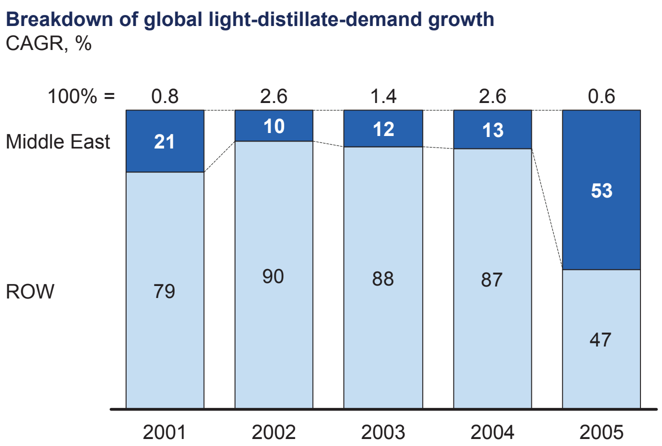
### HIGH OIL PRICES BOOST GDP GROWTH IN OIL-EXPORTING COUNTRIES AND MODERATELY REDUCE IT IN OTHERS




Source: Global Insight; MGI analysis

## Exhibit 45

### THE MIDDLE EAST – WITH THE HIGHEST SUBSIDIES – CONTRIBUTED HALF GLOBAL LIGHT-DISTILLATE GROWTH AT HIGH 2005 OIL PRICES



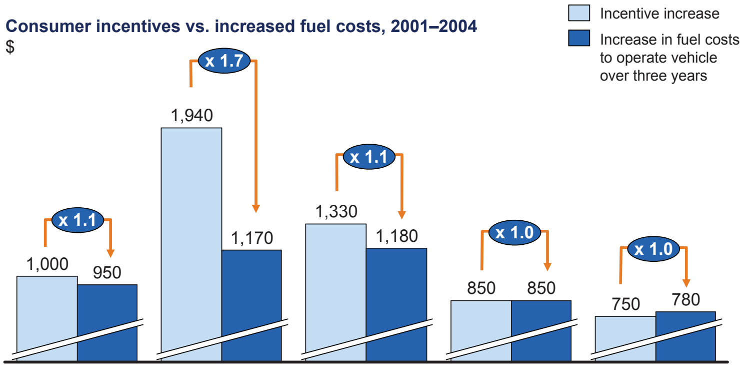

Source: BP Statistical Review; MGI analysis

### Shock absorbers in the United States: incentives and shifts in expenditure

In the United States, the first factor dampening the demand response in the face of rising fuel prices came in the form of rebates from auto manufacturers to consumers (Exhibit 46). When oil prices started to rise in 2003, US auto companies offered, or increased, rebates to encourage continued purchases of low-fuel-economy vehicles, especially light trucks (SUVs and pickups). Research by the University of Michigan Transportation Research Institute shows that, over the period 2001–2004, the increase in incentives was actually greater in value than the rise in fuel costs to operate the vehicle over three years.[18] For SUVs, the average incentive was close to 70 percent higher than the increase in fuel expenditure over that period, the equivalent of a $770 cash handout to buyers.

**Exhibit 46**

**IN THE UNITED STATES, OEM* INCENTIVES ON LARGER VEHICLES DELAYED THE IMPACT OF FUEL-PRICE INCREASES**




| 2004 | All segments | SUV | Pickup | CUV | Passenger car |
|---|---|---|---|---|---|
| **Market share** | 100 | 16 | 19 | 12 | 45 |
| **Cost for OEMs*** $ billion | 16.9 | 5.4 | 4.2 | 1.7 | 5.6 |

* Original Equipment Manufacturer.

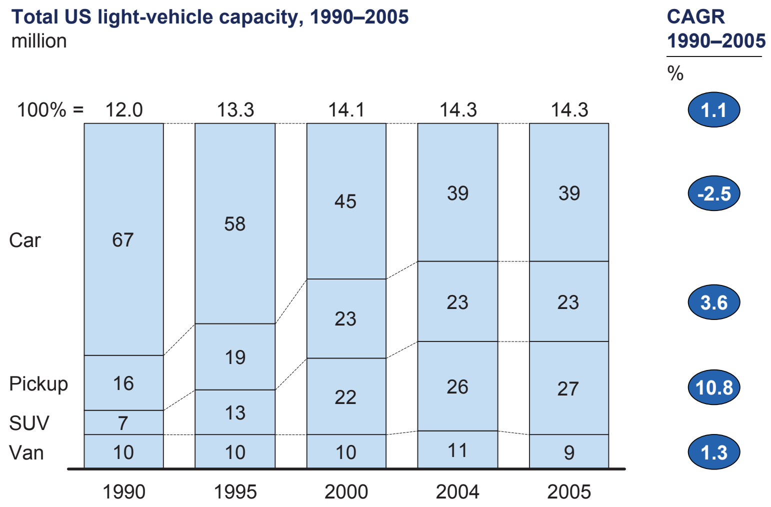
Source: Dr. W. S. McManus, A. Baum, R. Hwang, Dr. D. D. Luria, *In the Tank: How Oil Prices Threaten Automakers' Profits and Jobs*, Office for the Study of Automotive Transportation, University of Michigan Transportation Research Institute, July 2005; Ward's AutoInfoBank; MGI analysis

US automakers were willing to pay consumers to purchase light trucks because they had become increasingly dependent on them in terms of sales and even more in terms of profits. After 15 years of massive capacity buildup (Exhibit 47), SUVs and pickups came to represent more than 60 percent of total 2004 pretax profits for both GM and Ford and close to 50 percent for Daimler Chrysler. By contrast, this share was only 25 percent for Toyota.

18 Dr. W. S. McManus, A. Baum, R. Hwang, Dr. D. D. Luria, *In the Tank: How Oil Prices Threaten Automakers' Profits and Jobs*, Office for the Study of Automotive Transportation, University of Michigan Transportation Research Institute, July 2005.

## Exhibit 47

INCENTIVES WERE LINKED TO AUTO MANUFACTURERS' RAPID BUILDUP OF LIGHT-TRUCK CAPACITY




Source: Ward's AutoInfoBank; MGI analysis

In addition to benefiting from automaker incentives, other factors increased US consumers' disposable income, counteracting higher fuel prices. A strong housing market, which saw housing wealth increase by $5 trillion in 2004–2006 alone, gave consumers extra spending power to fund additional transportation-fuel expenditure (Exhibit 48).

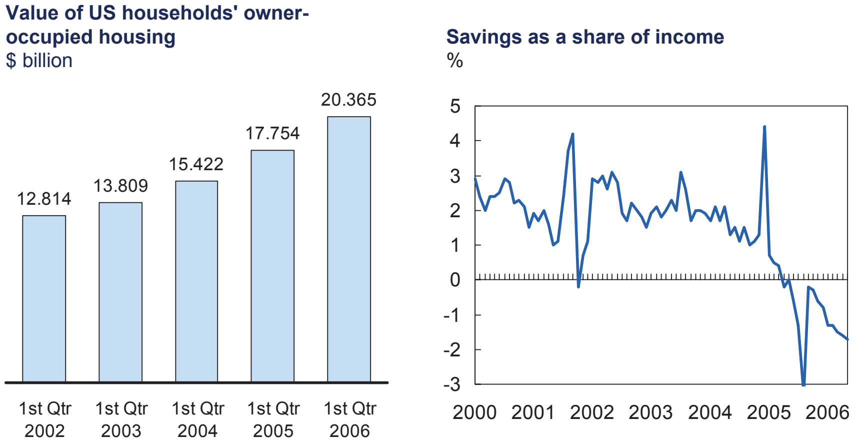
In addition, consumers also found ways to shift their overall spending on transportation to maintain their fuel consumption. With discounted prices, expenditure on new cars grew, reducing spending on used cars as well as the maintenance, finance, and rental of cars. Overall, this meant that although transportation-fuel expenditure increased markedly from 2002 to 2004, overall transportation spending was unchanged (Exhibit 49).

### Shock absorbers now wearing off, with an evident price response

In the United States, shock absorbers that shielded consumers from oil-price increases have dissipated over the past 18 months. After spending $17 billion on consumer incentives in 2004 alone, US auto manufacturers—saddled with huge losses—have rolled back consumer incentives and begun to shift their production toward more fuel-efficient vehicles. Housing prices have begun to level. Used-car prices, which had remained low in the early part of the decade and helped cushion gas-price increases, have risen.

## Exhibit 48

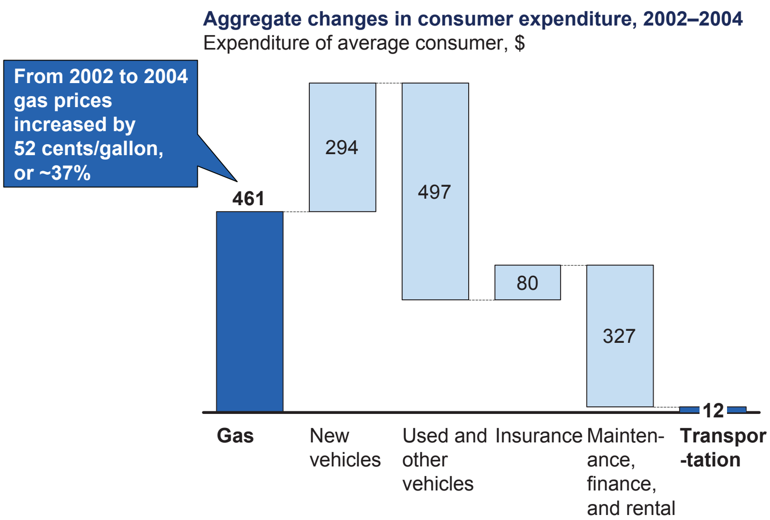
### STRONG HOUSING-WEALTH GAINS AND NEGATIVE SAVINGS RATE ALLOWED US CONSUMERS TO FUND HIGHER FUEL EXPENDITURE




Source: Federal Reserve Board, Flow of Funds; US Bureau of Economic Analysis; MGI analysis

## Exhibit 49

### US CONSUMERS' TRANSPORTATION SPENDING REMAINED UNCHANGED UNTIL 2004 DESPITE HIGHER GASOLINE PRICES

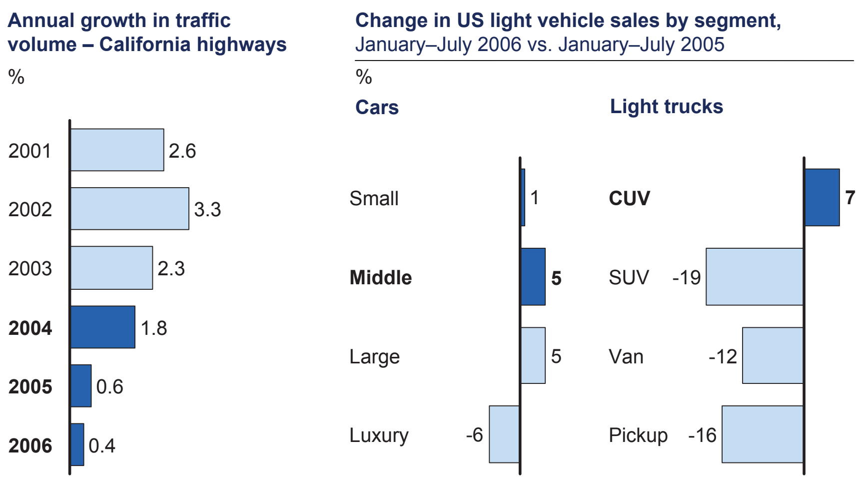



Source: U.S. Bureau of Labor Statistics; MGI analysis

As a result, consumers have started to reduce their transportation-fuel consumption by driving less and by buying more fuel-efficient cars. Traffic data shows a sharp slowdown of VMT growth. In fact, in 2006, average miles driven decreased for the first time in 25 years in the United States.[19] In California, 2001–2003 traffic volumes grew at a rate of 2.3 percent–3.3 percent and by 1.8 percent in 2004. However, by 2006, volume growth was virtually flat (Exhibit 50). US consumers are also purchasing more fuel-efficient cars, with a shift away from heavier SUVs and pickups to crossover utility vehicles (CUVs) and cars. While year-on-year SUV sales were down by more than 19 percent between 2005 and 2006, CUV sales grew by 7 percent. Hybrid sales have also been strong. The overall impact has been that US transportation-fuel demand has grown by only 0.9 percent in 2005 and by 0.8 percent in the first nine months of 2006, compared with 2.4 percent in 2004.[20]

**Exhibit 50**

HIGH GASOLINE PRICES HAVE RECENTLY SLOWED US VEHICLE TRAFFIC GROWTH AND IMPACTED THE LIGHT-VEHICLE SALES MIX




Source: California Department of Transportation; Ward's AutoInfoBank; MGI analysis

## V. ENERGY PRODUCTIVITY OPPORTUNITY

We identified two types of energy productivity opportunities in road transportation. For developing regions, the main opportunity lies in the removal of market-distorting fuel subsidies, which lead to overconsumption of transportation fuel. For

19 *Gasoline and the American People 2007: A CERA Special Report*, CERA, November 2006.

20 JODI database; MGI analysis.

developed regions, the opportunity comes from the adoption of additional fuel-saving technologies not already introduced in the MGI base-case scenario.

**Energy productivity opportunities**

In developing regions where fuel prices are subsidized, we estimate that approximately one-third of projected 2020 consumption could be cut by bringing fuel consumption per vehicle in line with the average of those regions without subsidies. In the Middle East, for example, we estimate that average fuel consumption per vehicle is more than double this average, even when taking into account the higher share of trucks in the region's total vehicle stock. The result is that the Middle East's road-transportation fuel demand could be cut by slightly over 50 percent by removing market-distorting subsidies. This removal would potentially also free up government budget resources. Iran, for example, is estimated to spend an amount equivalent to 16 percent of GDP subsidies on energy subsidies annually, with limited redistributive effect since only 0.1 percent of gasoline subsidies go to the poorest 10 percent of the population and 40 percent go the 10 percent wealthiest who can afford to drive large vehicles.[21]

The removal of fuel subsidies globally would lead to an estimated demand abatement of 3.0 million barrels per day of transportation fuels. This abatement breaks down between the direct impact of going from the subsidized price to a "base" oil-price equivalent of $30 (2.6 million barrels per day) and the indirect impact of demand reduction between the $30- and $50-oil scenarios based on MGI case studies (0.4 million barrels per day). Assuming the removal of 80 percent of subsidies would therefore lead to a demand reduction of 2.5 million barrels per day compared with MGI's base case (Exhibit 51). The bulk of this reduction would come from the Middle East, Mexico, and Venezuela (Exhibit 52).

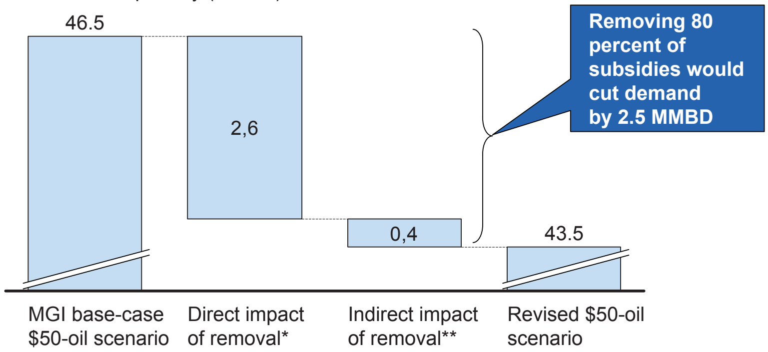
In developed regions, our base case assumes that auto manufacturers are already introducing most of the fuel-saving engine technologies with internal rates of return (IRR) of more than 10 percent for consumers. However, several available non-engine fuel-saving technologies with a 10 percent or higher IRR are not being introduced. These include, in particular, vehicle light-weighting through material substitution and the reduction of rolling resistance through improved aerodynamics. Introducing these technologies would achieve up to a 20 percent fuel-economy improvement for new vehicles by 2015. The impact on global vehicle fuel economy would be an estimated 5 miles per gallon, equivalent to 4.0 million barrels per day compared with the MGI base case, close to 9 percent of total 2020 demand.

21 A. von Moltke, C. McKee, T. Morgan, *Energy subsidies; lessons learned in assessing their impact and designing policy reform*, UNEP.

## Exhibit 51

### REMOVING FUEL SUBSIDIES WOULD CUT ROAD-TRANSPORTATION FUEL DEMAND BY 3 MILLION BARRELS A DAY

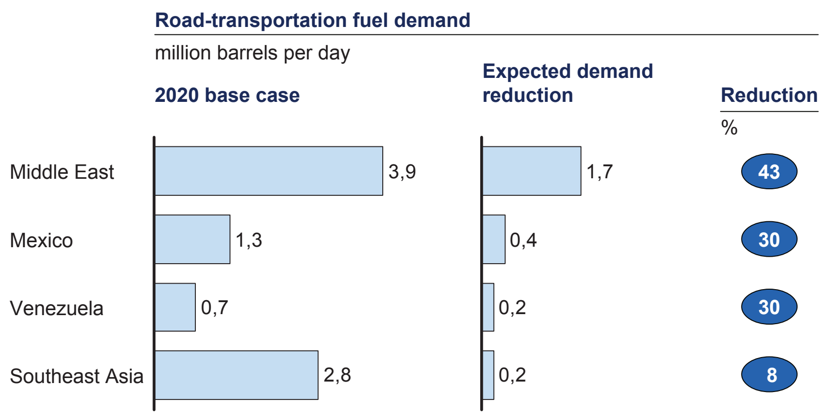
**Global road-transportation fuel demand, 2020**
million barrels per day (MMBD)




* Assuming that average VMT in regions with subsidies would come down to the average VMT in regions without subsidies.
** Assuming that the typical impact of oil-price increases (based on MGI case studies) applies fully to subsidized regions, which is not the case in the base version of the MGI model.
Source: MGI analysis

## Exhibit 52

### THE REDUCTION IN FUEL DEMAND WOULD COME MOSTLY FROM THE MIDDLE EAST, MEXICO, AND VENEZUELA




Source: MGI analysis

The fact that consumers consider many non-financial factors in their vehicle choice explains why not all positive-return fuel-saving technologies are adopted. Interestingly, the non-engine technologies are perceived to bear a degree of "consumer risk" for auto manufacturers, since consumers may associate heavier or larger vehicles with improved safety.

**Capturing the energy productivity opportunity**

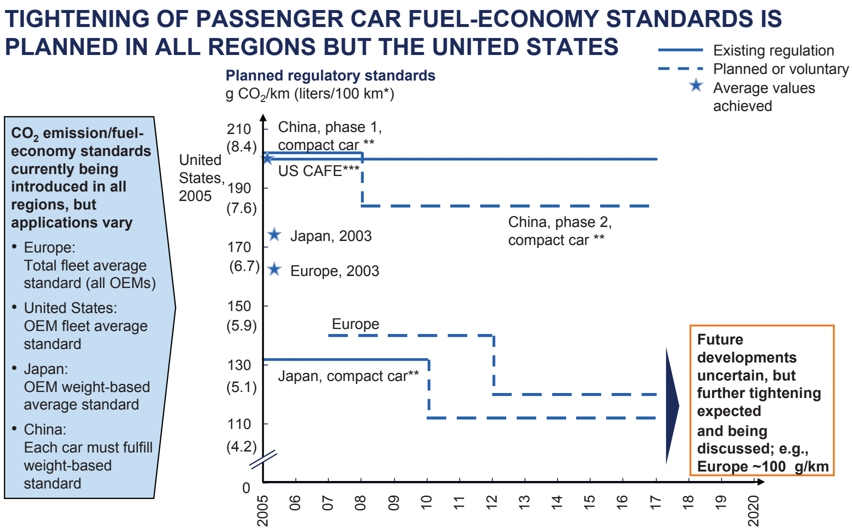
If policy makers are interested in improving the capture of energy productivity opportunities, they have a variety of options, some of which could be pursued in combination.

The removal of fuel subsidies could take the form of a gradual phase-out, designed to have a positive or neutral impact on the income of targeted population categories. This would make the operation more politically and socially acceptable by ensuring that subsidies' redistributive function is preserved or in fact enhanced.

To facilitate the introduction of non-engine fuel-saving technologies, policy makers have the option of tightening fuel-economy standards. This would eliminate the consumer risk for auto manufacturers by ensuring an industry-wide adoption of the technologies. Currently, standards are in place in all major regions, whether expressed in miles per gallon, liters per 100 km, or grams of $CO_2$ per km. Europe and Japan, whose standards are already more aggressive than those of the United States, have planned a further tightening of standards over the next five years (Exhibit 53). As an illustration, if the United States aligned its standards with those that prevail in Europe and Japan, global fuel economy would increase by four miles per gallon by 2020, equivalent to the total increase from non-engine technologies globally.

Because CAFE standards impact new vehicles only, they have a more immediate impact places like China, where new vehicle purchases over the next 15 years will represent the majority of the vehicle stock. Another option available to policymakers is to increase fuel taxes. In countries like the United States, with large installed vehicle base, taxes could have a more immediate impact as the vehicle stock will turn over more slowly.

## Exhibit 53




* 1 liter per 100 km = 23.7 g CO2 per 100 km for gasoline engines; fuel economy and CO2 emission standards have the same impact for cars.

** Values depend on vehicle weight; values here for compact car segment with cars weighing ~1,000 kg.

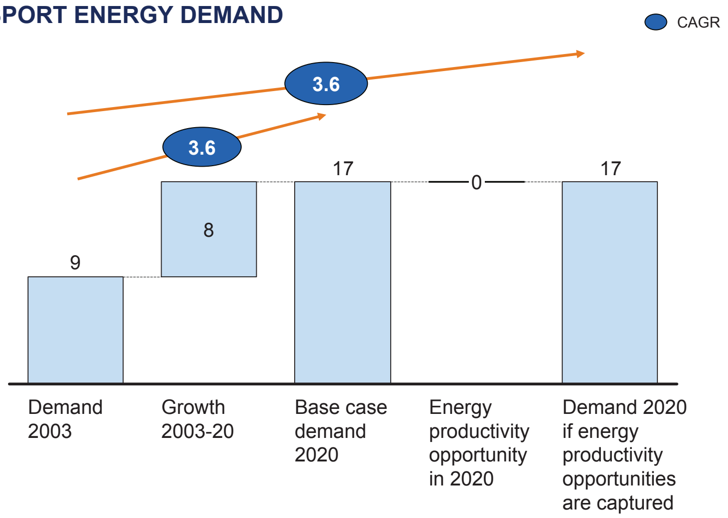
*** Corporate average fuel economy; SUV standards less stringent ~260 g CO2/km.

Source: World Resources Institute; ACEA; PEW Center on Global Climate Change; McKinsey DRIVE study

## Global air transportation sees high energy demand growth

- Air transportation is the fastest growing end-use segment, with 3.6 percent annual growth to 2020. By then, air transportation will account for 2.8 percent of global energy demand, up from 2.2 percent today, and the sector's demand for petroleum products will be equivalent to 8.2 percent of the global total.
- By 2020 energy demand in developing regions will almost catch up with that in developed regions, driven by strong growth in China of 6.7 percent annually.
- For every 1 percent of global GDP growth, we estimate 1.65 percent growth in air travel.
- Currently, the average new airplane consumes 40 liters of fuel per 1,000 seat miles traveled, but this will fall to 33 liters by 2020.
- There are currently limited additional available energy productivity improvements in air transport. Options for reducing air-transport energy demand would require reducing air travel or consumer comfort by increasing the number of seats on planes.

**AIR TRANSPORT ENERGY DEMAND**
QBTU




| | Demand 2003 | Growth 2003-20 | Base case demand 2020 | Energy productivity opportunity in 2020 | Demand 2020 if energy productivity opportunities are captured |
|---|---|---|---|---|---|
| **Global total** % | 2 | 4 | 3 | 0 | 3 |

Source: MGI Global Energy Demand Model

# Air-transportation sector

## I. EXECUTIVE SUMMARY

For all the publicity centered on the contribution of burgeoning air travel to energy demand and, by extension, $CO_2$ emissions, the global air-transport industry accounted for only 2.2 percent of worldwide energy demand and 6.6 percent of the global call on petroleum products in 2003.

Nevertheless, according to MGI's analysis, air transport will post the strongest demand growth of any energy end-use sector—3.6 percent a year on average from 2003 to 2020, leaving overall demand 82 percent higher. By 2020, air traffic will account for 2.8 percent of global energy demand, and demand for petroleum products from this sector will be equivalent to 8.2 percent of the global total. Historically, over 60 percent of global demand has come from the developed world, but, since 1994, developing economies have slightly increased their share and this trend will continue, with their share reaching 48 percent in 2020. The key drivers in this sector are demand for air travel, strongest in Southwest Asia and China and weakest in North America and Northwestern Europe, and annual improvements in fleet efficiency of some 1.7 percent.

Energy demand growth in the sector will depend on growth in the global economy and the oil price path. Under different scenarios, annual air-transportation energy demand growth could be as low as 2.3 percent and as high as 5.0 percent. Both GDP growth and oil price directly impact demand for air travel. For every 1 percent of global GDP growth, we estimate 1.65 percent growth in air travel. In contrast, the oil-price elasticity of air travel is low—every 1 percent increase in the oil price leads to a reduction of only 0.19 percent in air travel.

Only a limited number of currently available energy productivity improvements in air-transport remain uncaptured, as airlines consider fuel-cost management a key operational function. For this reason, there are limited positive-return opportunities to reduce air-travel energy demand outside of reducing air travel or increasing the number of seats on planes, which would compromise current levels of consumer comfort.

## II. AIR-TRANSPORT ENERGY DEMAND SIZE AND GROWTH

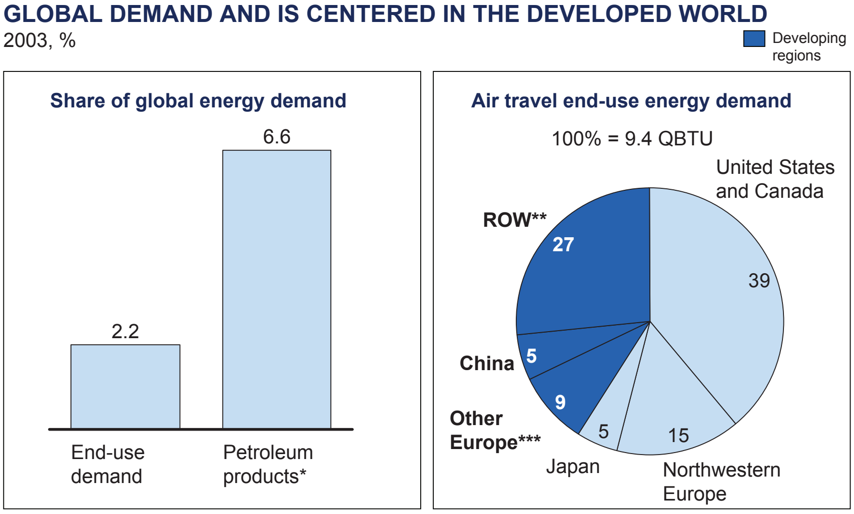
### Size and regional breakdown of energy demand, 2003

Air traffic accounted for 9.4 QBTUs (4.5 million barrels per day) of energy demand in 2003, corresponding to 2.2 percent of global energy demand and 6.6 percent of global demand for petroleum products. 59 percent of the sector's demand came from the developed world—with the United States and Canada contributing 39 percent, Northwestern Europe 15 percent, and Japan 5 percent. Emerging Europe[1] accounted for 9 percent of global demand and China for 5 percent, with the rest of the world consuming the remaining 27 percent (Exhibit 1).

**Exhibit 1**

**ENERGY DEMAND FROM AIR TRAVEL ACCOUNTS FOR 2.2 PERCENT OF GLOBAL DEMAND AND IS CENTERED IN THE DEVELOPED WORLD**

2003, %



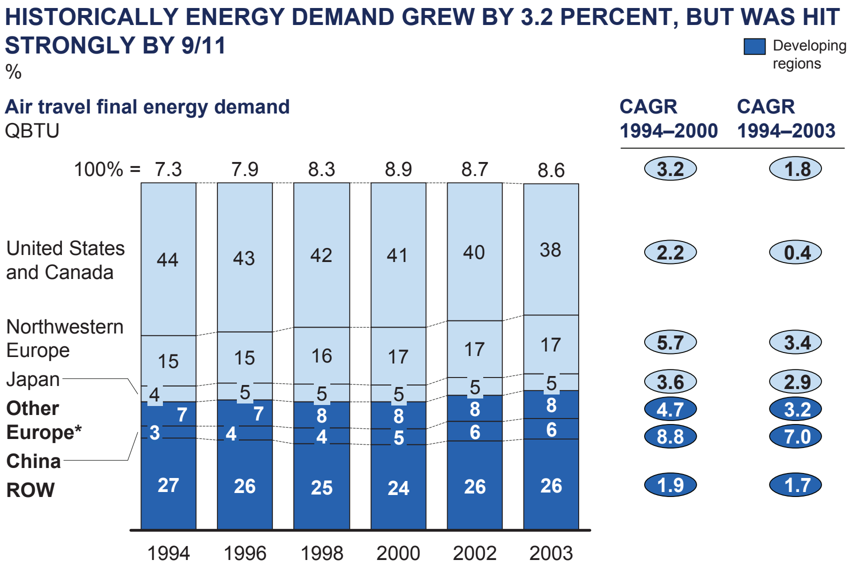

* Based on final energy demand.
** Rest of world.
*** Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.
Source: IEA; MGI analysis

In the 1994 to 2000 period, energy demand from the air-transport sector expanded strongly at an annual rate of 3.2 percent with the developing world slightly increasing its share of overall demand—China saw particularly strong

1 Including the Mediterranean, Baltic and Eastern Europe; and North Africa.

demand growth of 8.8 percent. Other centers of growth were Europe (Northwestern Europe 5.5 percent and emerging Europe 4.7 percent) and Japan (3.6 percent). Meanwhile, growth in the United States and Canada was less rapid at 2.2 percent, even before air-transport energy demand was dampened strongly by a downturn in air travel in the wake of the terrorist attacks on the United States in September 2001. Taking this into consideration, air-transport energy demand growth was only 1.8 percent in 1994–2003 (Exhibit 2).

**Exhibit 2**




* Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.
Source: IEA, MGI analysis

### Growth of energy demand and $CO_2$ emissions

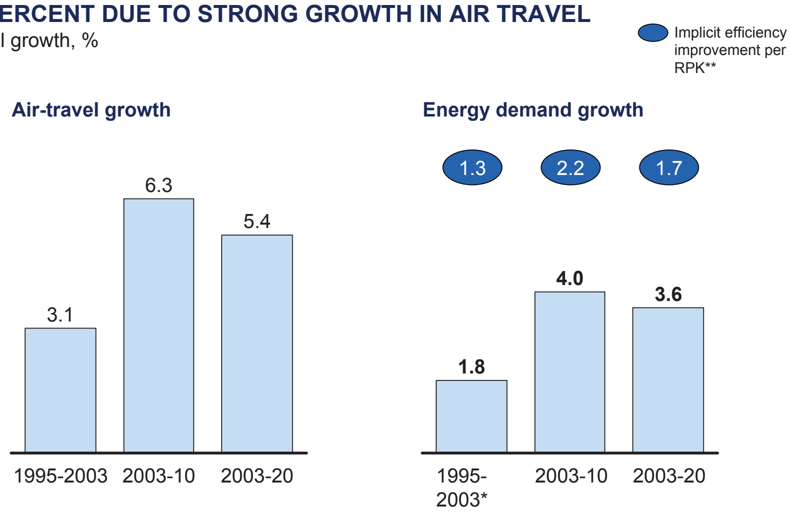
Going forward, we expect strong growth to continue through 2020, averaging 3.6 percent annually (Exhibit 3). This leads to an absolute increase in energy demand of 7.6 QBTUs, the equivalent of 3.9 million barrels per day—an 82 percent increase compared with the level of demand in 2003 (Exhibit 4). During this period, the developing world will start closing the energy demand gap with developed economies, driven by continuous, strong growth in China of 6.7 percent. Growth rates in developed economies will lag the global average, with 3.5 percent in Japan, 2.9 percent in Northwestern Europe, and 2.7 percent in the United States and Canada (Exhibit 5).

Energy demand from air transportation will grow from 2.2 to 2.8 percent of global energy demand between 2003 and 2020. Growth in petroleum products alone is even more pronounced—in 2020, 8.2 percent of overall petroleum demand will

## Exhibit 3

### GOING FORWARD ENERGY DEMAND WILL GROW SLIGHTLY HIGHER AT 3.6 PERCENT DUE TO STRONG GROWTH IN AIR TRAVEL

Annual growth, %




* Due to data limitations, the comparison to historical growth trends is established for final energy demand.

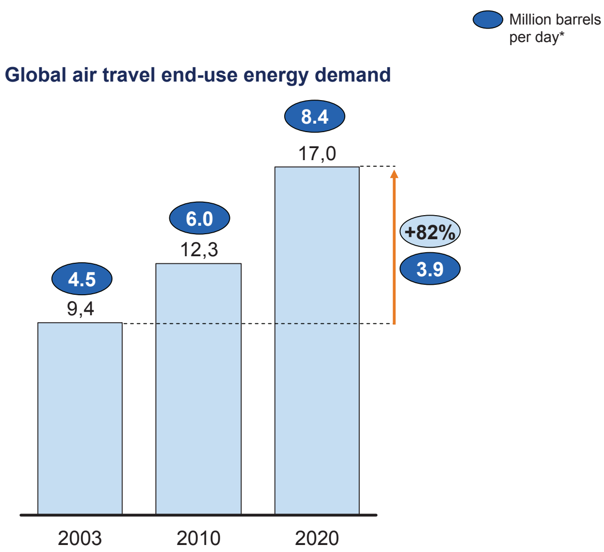
** Revenue Passenger Kilometer.

Source: IEA; Boeing Current Market Outlook 2005; MGI Global Energy Demand Model

## Exhibit 4

### BASE CASE PROJECTIONS LEAD TO ABSOLUTE GROWTH OF 7.6 QBTUS BY 2020

QBTU



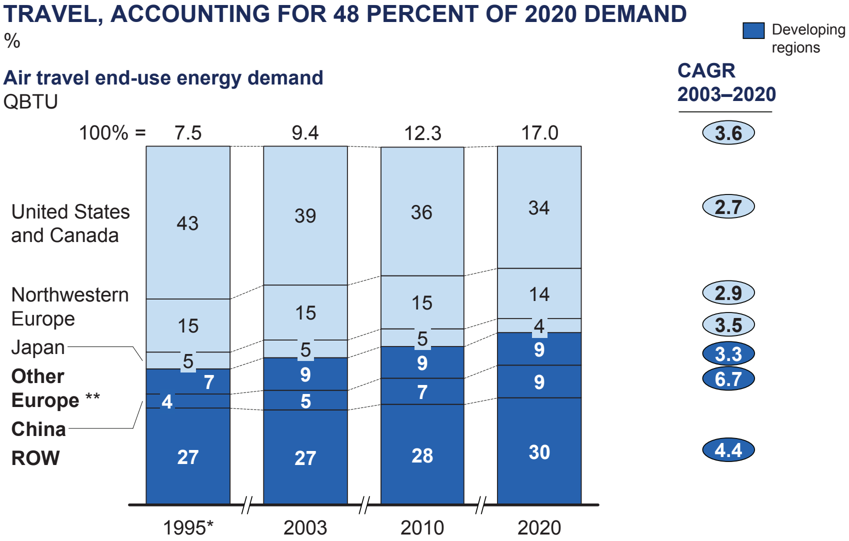

* Applying conversion factor 1.90 QBTU per MMBD of final jet fuel demand.

Source: IEA; MGI Global Energy Demand Model

## Exhibit 5

DEVELOPING REGIONS WILL CATCH UP IN ENERGY DEMAND FOR AIR TRAVEL, ACCOUNTING FOR 48 PERCENT OF 2020 DEMAND

%




* 1995 data reflects final energy demand, not end-use energy demand.

** Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.

Source: IEA, MGI Global Energy Demand Model

stem from air travel, compared with 6.6 percent in 2003. Given that there are no expected fuel-mix shifts in this sector, emissions of $CO_2$ move in parallel with fuel demand and we therefore expect emissions to grow by 3.6 percent from 650 million metric tons to 1,190 million metric tons.

Energy demand growth will, of course, depend on growth in the global economy and the oil price path. Under different scenarios, annual demand growth could be as low as 2.3 and as high as 5.0 percent—totaling between 13.8 and 21.5 QBTUs in 2020 (Exhibit 6). We discuss various scenarios and uncertainties in more detail in the following section.

## III. DRIVERS OF ENERGY DEMAND

From a microeconomic perspective, the main drivers of energy demand in the air-transport sector are demand for air travel on the one hand, and improvements in efficiency of the fleet on the other.

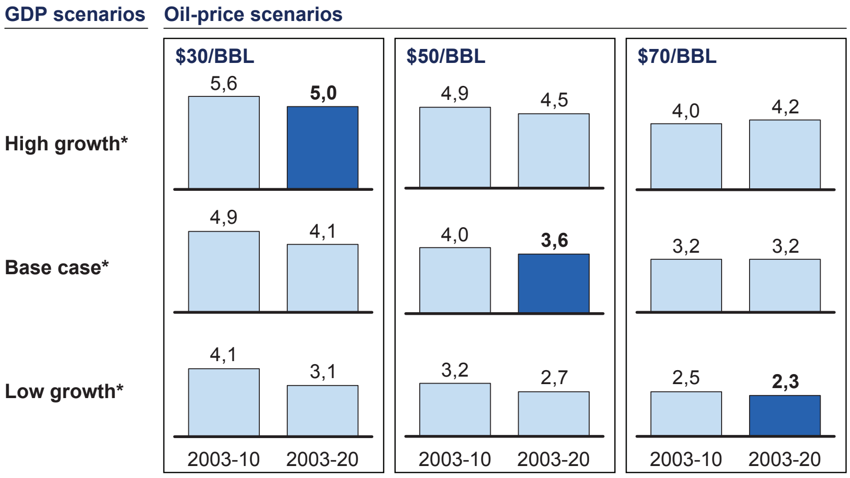
### Air-travel growth projected at 5.4 percent

Based on the Boeing Current Market Outlook 2005, we expect the volume of air travel to grow by 5.4 percent a year between 2003 and 2020, from 3,300 to 8,000 revenue passenger kilometers (RPKs), with even more pronounced expansion during the first seven years (between 2003 and 2010) of 6.3 percent. This is slightly higher than historic growth of 5.2 percent growth annually in the period

**Exhibit 6**

**ENERGY DEMAND GROWTH COULD SWING BETWEEN 2.3 AND 5.0 PERCENT TO 2020 DEPENDING ON GDP GROWTH AND OIL PRICE**

Annual growth, %




* Base-case growth of 3.2% globally; variations of ±2% for China and India, ± 1% for other developing regions, and ± 0.5% for developed economies.

Source: MGI Global Energy Demand Model

1985–2000. We chose this period for comparison in order to exclude the outlier year of 2001; however, the high growth rate for the 2003–2010 period is still inflated by the strong rebound in air travel—and therefore air-transport energy demand—in 2003–2004 after the sharp drop in air miles traveled after the 9/11 terrorist attacks in 2001. If we exclude 2003, we project that demand will grow at an annual rate of 5.0 percent in the 2004–2020 period, slightly below its historic growth trajectory (Exhibit 7).

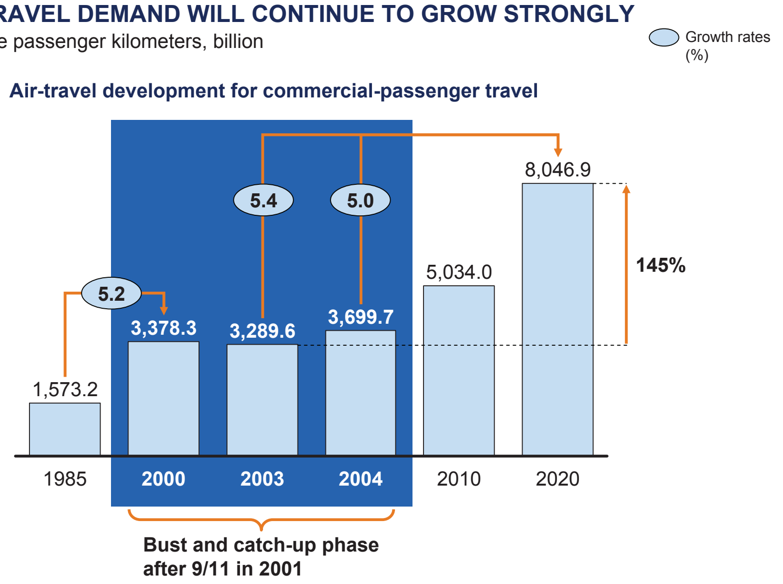
Boeing projections follow historic growth rates, and estimates are slightly lower than estimates by other entities, for instance, Airbus and Airline Monitor, which are respectively forecasting 5.3 and 5.4 percent growth rates (Exhibit 8).

Future centers of growth in terms of air miles traveled are Southwest Asia and China, with 9.1 percent and 8.7 percent annual growth in 2003–2020 respectively. We expect the lowest growth to be in North America and Europe (4.5 and 4.9 percent respectively) (Exhibit 9).

Interestingly, the rapid demand growth in airplane fuel creates new logistical challenges for the refining industry. While a standard refining configuration produces generally less than a 10 percent share of air-transportation fuels today, demand in several regions will exceed this proportion. This is especially the case

## Exhibit 7

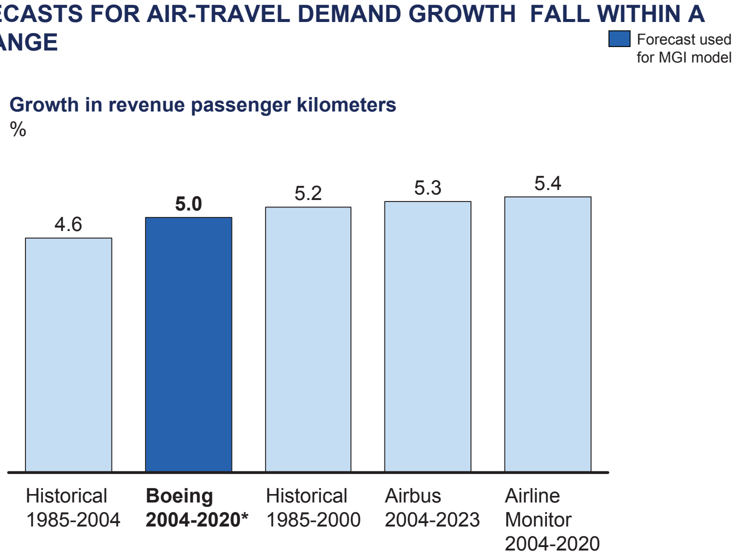
**AIR-TRAVEL DEMAND WILL CONTINUE TO GROW STRONGLY**
Revenue passenger kilometers, billion




Source: Boeing Current Market Outlook, 2005; MGI analysis

## Exhibit 8

**ALL FORECASTS FOR AIR-TRAVEL DEMAND GROWTH FALL WITHIN A CLOSE RANGE**




* Interpolated from 2004–2024 forecasts; taking 2003 as base year, forecast annual growth rate to 2020 is 5.4%.
Source: Boeing; Airbus; Airline Monitor; MGI analysis

## Exhibit 9

### AIR TRAVEL WILL GROW BETWEEN 4.5 AND 9.1 PERCENT WITH STRONGEST EXPANSION IN CHINA AND INDIA

%

| Boeing air-travel growth forecasts, 2003–2020 | | Adjusted* MGI growth forecasts | | |
|---|---|---|---|---|
| Region | CAGR | Region | CAGR | Average annual GDP growth multipliers |
| Africa | 5.8 | • South/East Africa | 5.5 | 1.46 |
| | | • West Africa | 6.3 | 1.39 |
| Central America | 5.0 | • Mexico | 4.9 | 1.21 |
| | | • Venezuela | 5.2 | 1.48 |
| China | 8.7 | • China | 8.7 | 1.19 |
| Former USSR | 5.1 | • Eastern Europe | 4.3 | 1.45 |
| | | • Black Sea/Caspian | 7.4 | 3.38 |
| | | • Russia | 5.7 | 1.93 |
| Europe | 4.9 | • Mediterranean /N. Africa | 5.3 | 1.91 |
| | | • Northwestern Europe | 4.7 | 1.21 |
| Middle East | 6.8 | • Middle East | 6.8 | 2.16 |
| North America | 4.5 | • Canada | 4.0 | 1.29 |
| | | • United States | 4.6 | 2.09 |
| Northeast Asia | 5.7 | • Japan | 5.3 | 1.89 |
| | | • Korea | 7.9 | 1.23 |
| South America | 8.0 | • South America Atlantic | 7.9 | 1.11 |
| | | • South America Pacific | 8.7 | 1.39 |
| Southeast Asia | 5.2 | • SE Asia/ Australia | 5.2 | 1.22 |
| Southwest Asia | 9.1 | • India | 9.1 | 1.20 |
| **Global** | **5.4** | | | **1.65** |

* Intraregion growth rates are adjusted to intraregion GDP growth forecasts.

Source: Boeing Current Market Outlook, 2005; MGI analysis

in Russia, the United States, and Northwestern Europe[2] where jet fuel will, by 2020, account for 14.0 percent, 11.3 percent, and 11.9 percent of total petroleum-products demand respectively (Exhibit 10). This suggests that the refining sector may need to make configuration adjustments and accelerate interregional transportation of refined products.

### Air-fleet efficiency growth projected at 1.7 percent

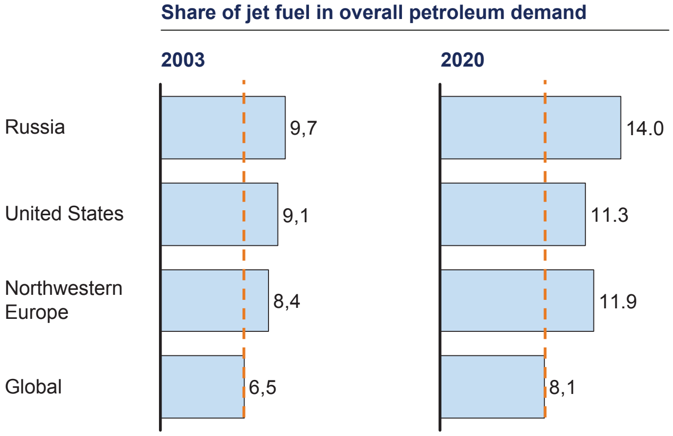
We anticipate that the efficiency of the global air fleet will increase by 1.7 percent a year for each RPK traveled in 2003–2020. This is slightly higher than the historical rate of efficiency improvement of 1.3 percent in 1995–2003. In the period ahead, efficiency grows much more quickly in the early years up to 2010 due to a spike in fleet turnover. Furthermore, most of the gains derived from increasing load factors also appear in the period to 2010 (Exhibit 11).

We prefer to use RPK, as opposed to the efficiency per average seat kilometer traveled (ASK) measure because, while consumption per ASK only tracks improvements in the technical efficiency of fleets, consumption per RPK also takes into account the more efficient use of capacity—i.e., the less airplanes fly with empty seats, the higher their load factors and levels of efficiency. Our

2 Includes Belgium, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Switzerland, and the United Kingdom.

## Exhibit 10

### SHARE OF JET FUEL IN PETROLEUM PRODUCTS WILL INCREASE SIGNIFICANTLY – WITH POTENTIAL STRAIN ON REFINING

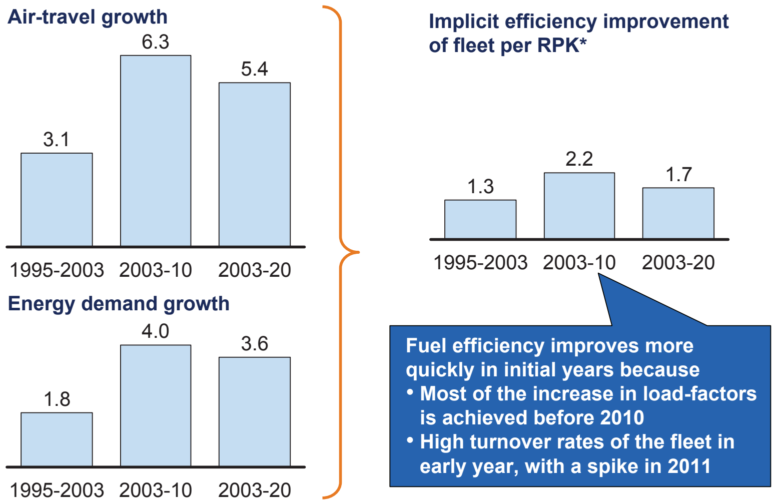



Source: IEA; MGI Global Energy Demand Model

## Exhibit 11

### EFFICIENCY OF FLEET WILL IMPROVE SLIGHTLY MORE QUICKLY THAN HISTORICALLY

Annual growth, %




* Revenue passenger kilometers.

Source: IEA; Boeing Current Market Outlook 2005; MGI Global Energy Demand Model

1.7 percent average annual efficiency improvement combines estimates for both improved technical efficiency and load factors.

Using the estimate by the Energy Information Agency (EIA) for the US market, which is very close to the historic global efficiency-improvement path (Exhibit 12), we project that the annual technical efficiency of the average new airplane in the global fleet will increase by 1.3 percent per annum in 2003–2020. Currently, the average new airplane consumes 40.5 liters of fuel per 1,000 seat miles traveled, but this will have fallen to 33.3 liters by 2020. Within the aggregate efficiency figures in each aircraft-vintage year, there are large differences—for instance, regional jets are generally less efficient and consume on average 55.0 liters per 1,000 seat miles, while narrow- and wide-body planes consume only 36.2 and 37.3 liters respectively (Exhibit 13).

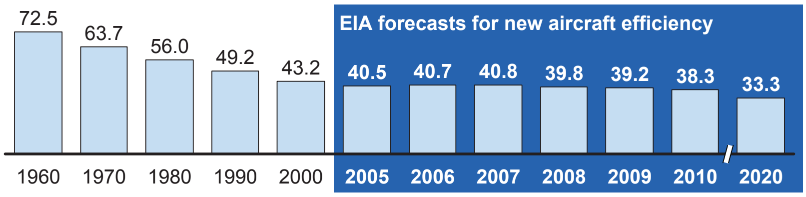
**Exhibit 12**

**FUEL EFFICIENCY PER VINTAGE YEAR WILL INCREASE AT HISTORIC IMPROVEMENT RATES**

**Historical improvements**
- IATA determines fuel efficiency improvement of 17.21% from 1996 to 2005 on entire fleet
- This corresponds to a **1.37%** annual efficiency improvement of the fleet
- However, efficiency improvements of the fleet do not equal efficiency improvements of the respective vintage model. We assume conservatively a **1.30%** annual increase in efficiency

**Future efficiency improvements**
- EIA estimates fuel efficiency per seat mile traveled for each future new vintage model year
- Average efficiency improvement 2005-2020: **1.31%**
- We apply this annual efficiency improvement to the considered period of 2003-2020

**Fuel efficiency per vintage model**
Fuel consumption in liter per 1,000 seat kilometers traveled




Source: International Air Transport Association (IATA); Energy Information Administration (EIA)

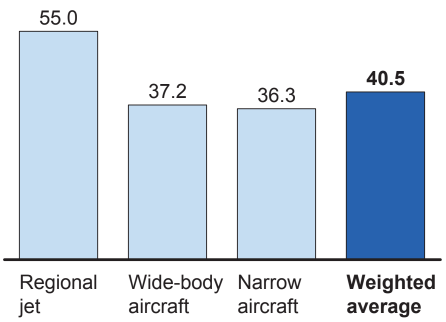
Further efficiency gains will be achieved by utilizing newer, more efficient planes more often. Based on data from Airline Monitor, we assume that each year, new planes are, on average, 0.2 percent faster, have 0.4 percent more seats, and fly 0.6 percent more hours per day (Exhibit 14).

To determine the share of each aircraft-vintage year in the overall stock, we apply a vintage model, looking at the age distribution of the global stock of planes that is currently in use. Combining this with the expected retirement rate for each year a plane ages, we can derive the capacity of the existing fleet at any point in

## Exhibit 13

### HOWEVER, SIGNIFICANT EFFICIENCY DIFFERENCES EXIST AMONG AIRCRAFT TYPES

**New aircraft efficiency, 2005**
liters per 1,000 seat kilometers

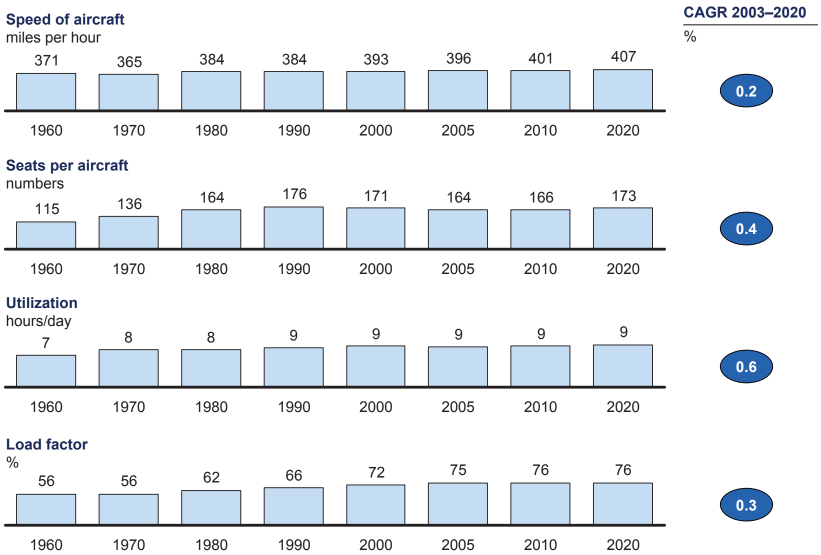



- **Significant efficiency differences exist between different aircraft types**
- **Weighted average efficiency of new aircraft accounts for respective shares in new aircraft stock**
- **We assume development of the US market to be representative globally**

Source: Energy Information Administration – National Energy Modeling System (NEMS)

## Exhibit 14

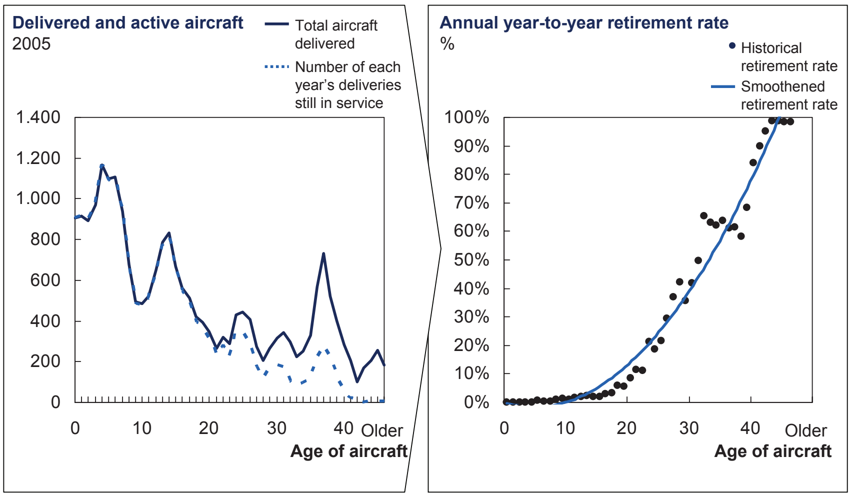
### NEWER, MORE EFFICIENT PLANES WILL BE USED MORE, AS USE AND PERFORMANCE GROW SLIGHTLY




Source: Airline Monitor, January/February 2006 time (Exhibit 15).[3] The number of new planes per year is determined by matching existing capacity with the required capacity to satisfy our air-traffic demand projections. Our estimate for the annual efficiency improvement of the global fleet—1.3 percent—is slightly higher than the EIA's projection of 1.2 percent for the US fleet for the same period. The reason for this difference is that global air-traffic growth will be higher than that in the United States and therefore the global fleet will have a higher share of newer, more efficient planes than the United States alone.

**Exhibit 15**

### PLANES OLDER THAN TEN YEARS ARE GRADUALLY RETIRED




Source: Airline Monitor, January/February 2006

## IV. KEY UNCERTAINTIES AROUND THE MGI BASE-CASE SCENARIO

Energy demand from air travel reacts strongly to changes in GDP growth with a 1.8 percent difference in annual demand growth rates between our low- and high-growth scenarios, equivalent to a 5.3 QBTUs difference in 2020. Air-travel energy demand also reacts moderately to changes in the oil price—there is a 0.9 percent difference in demand growth rates between the oil price at the $30-a-barrel scenario and the $70-a-barrel scenario—equivalent to 2.4 QBTUs by 2020.

3 The retirement rate is determined for each age group based on historic data. For example, we assume that, until the age of 10 years, all planes are still in service; at age 20, this figure falls to 88 percent; at age 30, it declines to 67 percent, and so on.

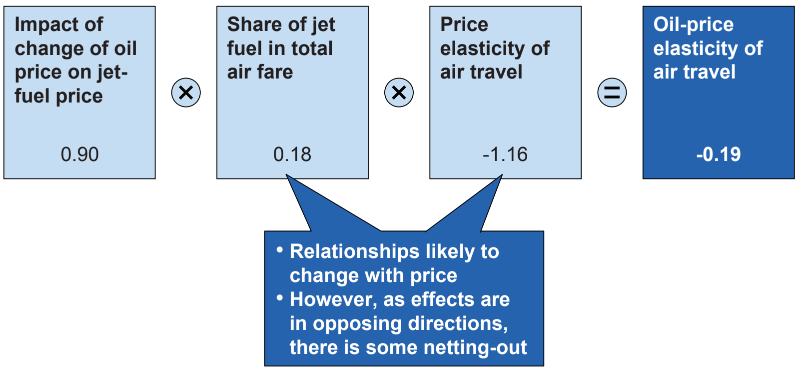
**GDP and oil price directly impact demand for air travel**

Based on Boeing's air-traffic forecasts and underlying GDP growth assumptions, we have estimated regional multipliers identifying the relationship between GDP growth and growth in air-travel demand and conclude that the elasticity of air-travel demand to GDP growth is some 1.65—i.e., for every 1 percent growth in global GDP, we expect 1.65 percent growth in air travel (see Exhibit 9).

We estimate the response of air-travel demand to changes in the oil price at minus 0.19 (Exhibit 16). Three components determine the oil-price elasticity of air-travel demand: the impact of the prevailing crude-oil price on jet-fuel prices; the relationship between the jet-fuel price and air fares; and the price elasticity of air travel.

**Exhibit 16**

**OVERALL OIL-PRICE ELASTICITY OF AIR TRAVEL IS -0.19**




Source: MGI analysis

- Analyzing the correlation between spot prices in jet fuel and West Texas Intermediate (WTI) crude oil in 1990–2006, we identify an elasticity of 0.9 (Exhibit 17). In other words, a 10 percent increase in the WTI price results in an increase in the jet-fuel price of 9 percent. The slightly smaller reaction of jet-fuel price to oil price is intuitive, considering that refining costs remain constant.

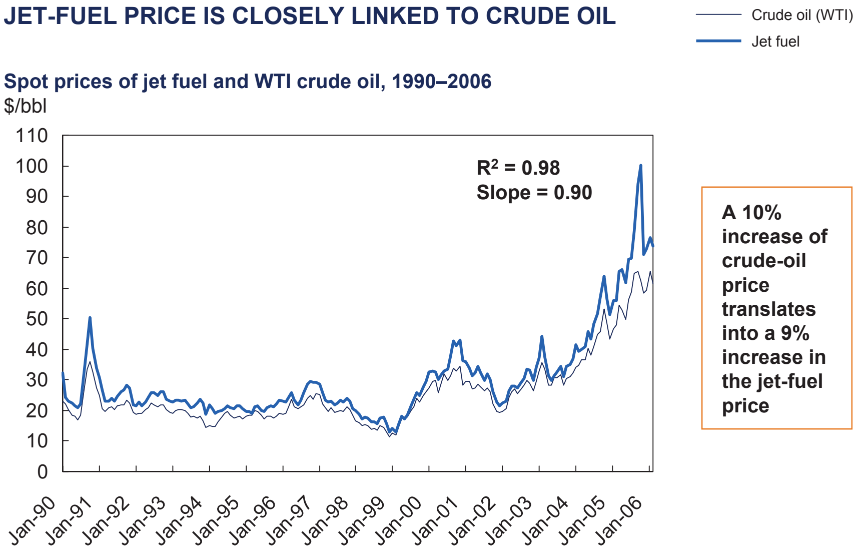
- An analysis of International Air Transport Association (IATA) data on global aviation revenues in 2002–2006 found that fuel expenses account for some 18 percent of total airfares (Exhibit 18).

## Exhibit 17

### JET-FUEL PRICE IS CLOSELY LINKED TO CRUDE OIL

**Spot prices of jet fuel and WTI crude oil, 1990–2006**

$/bbl




**A 10% increase of crude-oil price translates into a 9% increase in the jet-fuel price**

Source: Platts

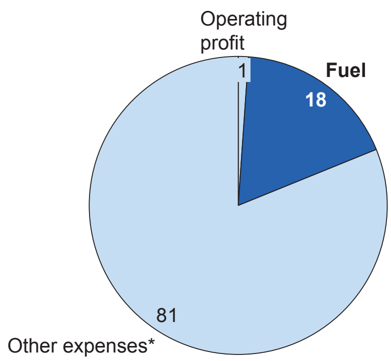
## Exhibit 18

### FUEL EXPENSES ACCOUNT FOR SOME 18 PERCENT OF TOTAL AIR FARE

2002–2006F, %

**Revenues of global commercial aviation**

100% = $ 1868 billion




* Including, e.g., handling, airport fees, maintenance, facilities and professional services, navigation, landing fees, catering, in-flight entertainment, information, technology, marketing, insurance.

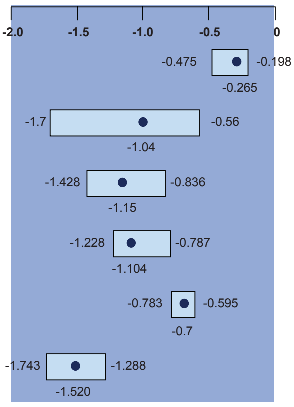
Source: IATA June 2006 Industry Fact Sheet

- We base our estimate of the price elasticity of air travel on a study by the Canadian Department of Finance, which evaluated up to 49 estimates of price elasticities in different market segments (long haul versus short haul, international versus domestic, business versus leisure). A weighted average of these estimates gives us an overall price elasticity of minus 1.16 (Exhibit 19).

**Exhibit 19**

**ACADEMIC STUDIES SHOW PRICE ELASTICITY OF AIR TRAVEL SLIGHTLY ABOVE 1**

Academic studies indicate range of elasticities depending on segment . . .




| Market segment | Number of studies | Number of estimates | Range of elasticities (low / mean / high) | . . . weighting segments by share of total travel . . . |
|---|---|---|---|---|
| 1. Long-haul* international business | 2 | 16 | -0.475 / -0.265 / -0.198 | 2.6% |
| 2. Long-haul* international leisure | 6 | 49 | -1.7 / -1.04 / -0.56 | 7.1% |
| 3. Long-haul** domestic business | 2 | 26 | -1.428 / -1.15 / -0.836 | 2.6% |
| 4. Long-haul** domestic leisure | 2 | 6 | -1.228 / -1.104 / -0.787 | 4.0% |
| 5. Short-haul*** business | 3 | 16 | -0.783 / -0.7 / -0.595 | 32.6% |
| 6. Short-haul*** leisure | 3 | 16 | -1.743 / -1.520 / -1.288 | 51.1% |

. . . allows to determine overall elasticity: **-1.16**

* Flights of more than six hours' air time.
** Flights up to six hours' air time, i.e., from coast to coast in United States.
*** Flights up to two hours' air time.

Source: Canadian Department on Finance: Air travel demand elasticities: Concepts, Issues and Measurement; US Office of Travel and Tourism Industries; Travel Industry Association of America

**GDP and oil price only indirectly impact global air-fleet efficiency**

Changes in GDP growth impact the efficiency of the air fleet asymmetrically: in a high-growth scenario, we estimate an annual improvement rate of 1.8 percent compared with 1.6 percent in a low-growth scenario. Changes in oil price have only a minor impact. The improvement rate remains more or less unchanged at 1.7 percent in a $70-a-barrel scenario and a $30-a-barrel scenario.

These changes impact the efficiency of the fleet only indirectly by affecting the share of new aircraft in the overall stock. In other words, a low-oil-price and high-GDP-growth scenario fosters high air-travel demand growth, and the share of new, more efficient planes increases.

Changes in oil price or GDP growth do not directly impact the rate of efficiency improvement of new planes or the retirement rate of existing capacity. Indeed, we believe that the rate of efficiency improvements of new airplanes is independent of changes in oil price or GDP growth, and that "economic potential" of an estimated 1.3 percent acts as a cap on the annual efficiency improvements of jet engines. Further enhancements would require the use of lighter, higher-quality materials, but processing such materials is not economical, even in a high-oil-price environment.

Nor do we believe that changes in the oil price have a significant effect on aircraft retirement rates. Although fuel expenses account for a significant share of overall operating costs, many other factors determine decisions about the deployment of individual aircraft, such as matching aircraft capacity (number of seats, for instance) to the requirements of a specific route; although other planes may be more economical on average, their specifications may not fit.

### V. ENERGY PRODUCTIVITY OPPORTUNITY

Our analysis shows that only a limited number of currently available energy productivity improvements in air-transport have not already been captured, as airlines consider fuel-cost management a key operational function. Reducing energy demand from the sector would require either reducing air-travel demand or reducing consumer comfort by increasing the number of seats in airplanes. Higher oil prices are unlikely to shift demand down significantly, because of the low oil-price elasticity of air-transport demand.

## Industrial energy demand continues shift to developing regions

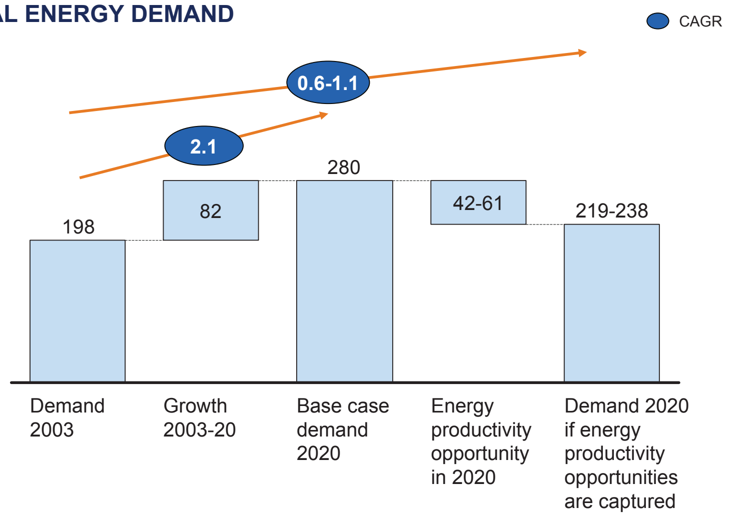
- Industrial energy demand is expected to grow at 2.1 percent a year worldwide to 2020. China, growing at 3.8 percent a year, will reach 23 percent of the global total by 2020; demand is driven especially by increasing chemicals and steel production.

- $CO_2$ emissions will grow at a rate of 2.0 percent per year—slower than the 2.7 percent registered by consumer-driven industries. The chemicals and steel production sectors together represent 13 percent of total energy-related $CO_2$ emissions in 2020, with chemicals accounting for 2.5 gigatons and steel for 2.2.

- Capturing energy productivity improvement opportunities in the industrial sector would reduce demand in 2020 by between 16 and 22 percent, with greater potential in developing regions. Large opportunities include heat recovery and combined heat and power systems.

- Because of cumulative risks related to costs, future prices, and operations, industrial companies sometimes apply IRR hurdle rates of 20 percent or more to plant-level investment projects. These high hurdle rates are also applied to energy-saving projects, even though they may not be as risky.

**INDUSTRIAL ENERGY DEMAND**
QBTU




| | | | | | |
|---|---|---|---|---|---|
| **Global total** % | 47 | 43 | 46 | 38 | 48 |

Source: MGI Global Energy Demand Model

# Industrial sector

## I. EXECUTIVE SUMMARY

MGI's analysis of industrial end-use energy demand focuses on three major segments: selected petrochemicals (ethylene and its derived products, nitrogenous fertilizers, and chlorine-caustic), steel, and pulp and paper. We chose these because of the magnitude of their energy demand—together they cover 31 percent of current global industrial energy demand, and account for close to 50 percent of the growth we project in our base-case scenario to 2020.

Energy demand in the industrial sector represented 198 QBTUs of end-user demand in 2003 globally, or 47 percent of total energy demand. We forecast energy demand from the industrial sector to grow at an annual rate of 2.1 percent per year to 2020. Strongest growth will come from developing regions, at 2.6 percent per year on average, compared with 0.7 percent per year for developed regions. There will be a shift in the industrial fuel mix, with petroleum products and coal claiming rising shares at the expense of natural gas and electricity. This will be caused by faster growth in the production of petroleum-intensive chemicals and coal-intensive steel and by increasing shares of industrial output coming from the petroleum-intensive Middle East and coal-intensive China.

Energy demand in the industrial sector is relatively sensitive to GDP growth, with demand rising by an additional 0.6 percent for each additional 1 percent of growth. Oil-price fluctuations have a smaller impact, first because end-use consumers have low price elasticity to intermediate basic-materials prices; second, because switching to less energy-intensive materials is limited; and third, because only a limited portion of industry has short-term energy-switching capabilities. To have a material impact on energy demand, price changes have to be significant and sustained. Only then will industry commit to a higher budget for energy-saving projects offering relatively distant payoffs.

We estimate the untapped economic potential for industrial energy productivity improvement to be 16–22 percent of industrial demand in 2020. There are many barriers to tapping this potential: energy costs are fragmented across operating units, and industrial companies, many of which are government-owned, typically use high hurdle rates (around 20 percent internal rate of return [IRR]) to evaluate capital investments, including energy-saving projects.

To overcome such hurdles, policy makers can introduce financial incentives, both negative (taxes) and positive (subsidies), to stimulate energy-saving investments. But, unless incentives are harmonized across countries, they risk triggering industry relocation rather than significant energy productivity improvements. Another approach is for policy makers to provide information on energy-conservation technologies, including cost-benefit analyses. And they can use standards and government purchasing guidelines more widely, while ensuring that these are not so specific as to skew incentives.

## II. INDUSTRIAL SECTOR ENERGY DEMAND SIZE, GROWTH, AND FUEL MIX

### Size and regional breakdown of energy demand, 2003

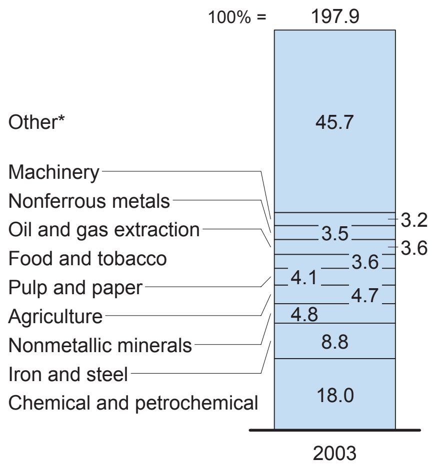
Energy consumption in the industrial sector represented 198 QBTUs of end-user demand in 2003 globally, or 47 percent of total energy demand. This demand is relatively fragmented across a large number of industries (Exhibit 1). Overall, however, the top consumers of energy in the industrial sector are heavy basic-materials segments such as chemicals, steel, pulp and paper, and cement.

Approximately one-third of global industrial energy demand comes from developed regions; another third comes from China, Russia and developing Europe; the last third comes from all other countries (Exhibit 2). In terms of regional breakdown, the industrial sector has some unique characteristics. In contrast to sectors like residential, commercial, or transportation, the industrial sector produces goods that are often traded globally. This allows industries to establish themselves in regions that serve foreign demand by offering lower energy, materials, labor, or capital costs. For this reason, any comparison between regional industrial energy demand and the underlying local economy needs to take into account the trade in industrial goods.

## Exhibit 1

### HEAVY BASIC-MATERIALS SEGMENTS DOMINATE INDUSTRIAL END-USE ENERGY DEMAND IN 2003

%, QBTU




Energy consumption in the industrial sector is relatively fragmented, with most of the demand in the heavy basic-materials segments

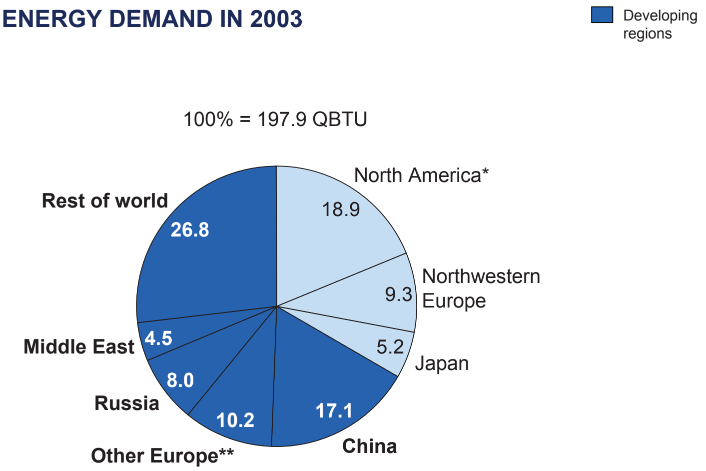
* "Other" includes non-specified industries and industries with <3% of total industrial energy demand.

Source: IEA; MGI Global Energy Demand Model

## Exhibit 2

### DEVELOPING REGIONS REPRESENTED TWO-THIRDS OF GLOBAL INDUSTRIAL ENERGY DEMAND IN 2003

%




* US and Canada.

** Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.

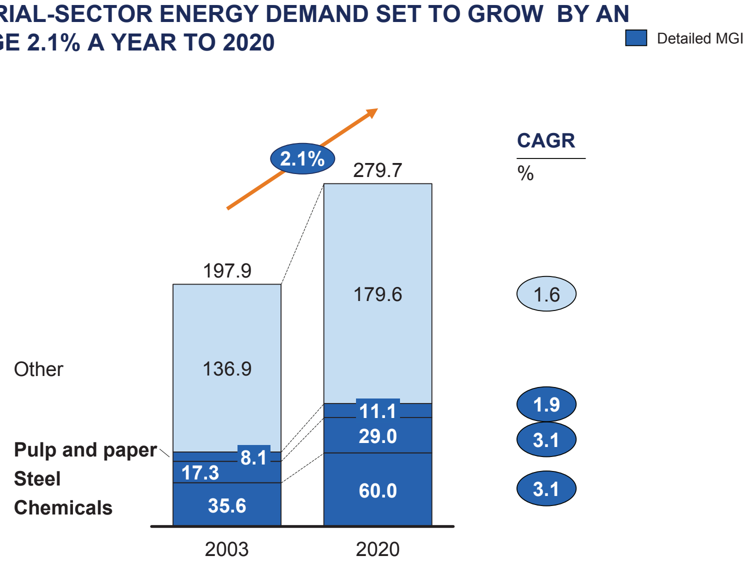
Source: IEA; MGI Global Energy Demand Model

### Growth of energy demand

We expect the industrial sector's overall energy demand to grow at an average compound annual rate of 2.1 percent over the next 15 years (Exhibit 3). Large energy-consuming basic-materials industries will see higher-than-average energy demand growth—particularly the chemicals and steel industries, growing at 3.1 percent per year. In fact, these two industries alone will represent almost one-third of industrial demand by 2020, up from 27 percent today. Continued industrialization and urbanization in developing regions will increase basic-materials demand—for example, China's steel energy demand will grow at 7.2 percent per annum to 2020, and its chemicals energy demand at 5.7 percent. In section III, we present detailed case studies on the chemicals, steel, and pulp and paper sectors.

**Exhibit 3**

**INDUSTRIAL-SECTOR ENERGY DEMAND SET TO GROW BY AN AVERAGE 2.1% A YEAR TO 2020**
QBTU



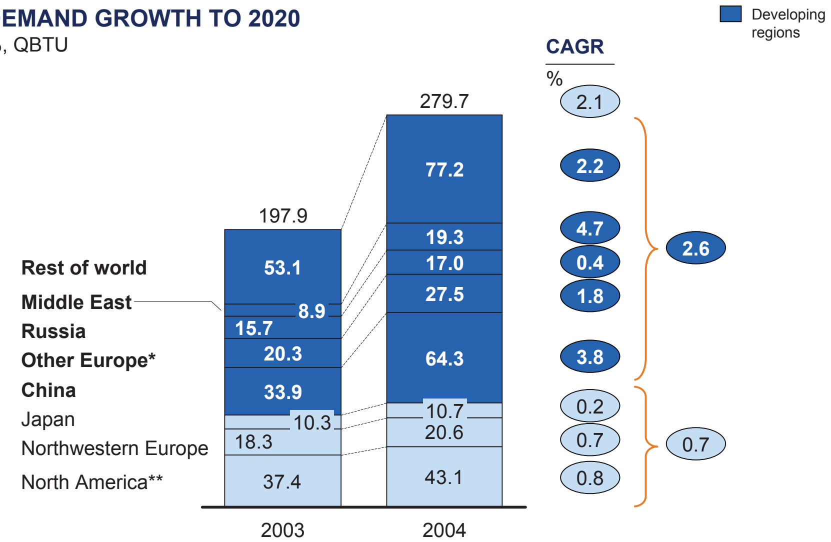

Source: IEA; MGI Global Energy Demand Model

Over the next 15 years, industrial energy demand will grow worldwide, but developing regions will post the fastest growth rates at 2.6 percent per year on average, compared with 0.7 percent per year for developed regions (Exhibit 4). The rapid increase in energy demand in developing regions will be driven by fast growth rates in domestic GDP, as well as a continuation of the current trend for industries to relocate to these regions to benefit from lower production costs. Unsurprisingly, overall energy demand in China grows briskly at 3.8 percent per year to reach 23 percent of global industrial energy demand by 2020. Interestingly, the fastest growth will be in the Middle East as a result of high GDP growth driven by high oil prices and government investment. Total industrial energy demand in the region will grow at 4.7 percent per annum to 19.3 QBTUs in 2020, largely fueled by the chemical industry's growth of 6.2 percent per annum. Russia and Eastern Europe are the only developing regions that will lag behind this rapid growth trend. Their energy demand will increase by less than 1 percent per year, as energy-efficiency improvements and a change in industry mix offset most of the growth in industrial-sector energy demand.

**Exhibit 4**

**DEVELOPING REGIONS WILL POST THE FASTEST INDUSTRIAL ENERGY DEMAND GROWTH TO 2020**

%, QBTU




* Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.

** US and Canada.

Source: IEA; MGI Global Energy Demand Model

### Sector fuel mix

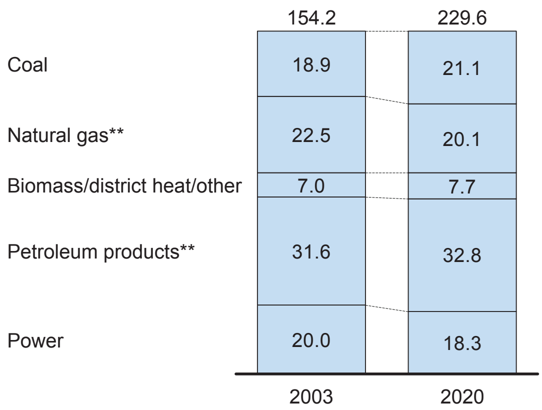
Petroleum products represented close to one-third of industrial-sector energy demand in 2003. The next largest end-user was natural gas with 22 percent, followed by power with 20 percent, coal with 19 percent, and other fuels, largely biomass, with 7 percent. Going forward, petroleum products and coal will increase their shares by 1 and 2 percentage points respectively, while natural gas and power will both lose 2 percentage points (Exhibit 5).

The fuel mix in different regions varies markedly, depending on a particular region's industry mix as well as its endowment of energy resources. While the Middle East relies heavily on natural gas and petroleum products, which will together account for 83 percent of total fuels in 2020, 52 percent of China's industrial energy will come from coal in 2020. India will also continue to rely heavily on coal, which will supply 32 percent of its 2020 industrial energy needs (Exhibit 6).

## Exhibit 5

### PETROLEUM PRODUCTS AND COAL WILL BUILD SHARE OF FUEL MIX SLIGHTLY, WHILE NATURAL GAS AND POWER WILL EDGE LOWER

**Global fuel mix of industrial final energy demand*, 2003–2020**
QBTU, %

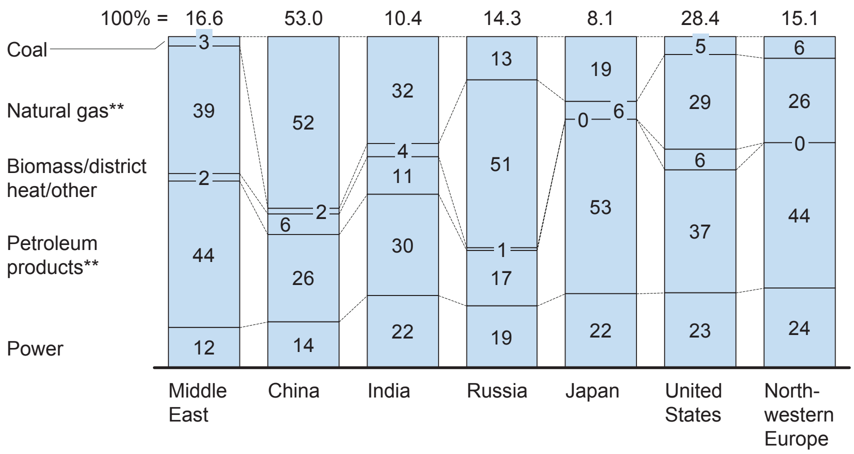



* Final energy demand does not include transformation losses as end-user energy demand does.
** The natural-gas category includes only methane; ethane is included in the petroleum-products category.
Source: MGI Global Energy Demand Model

## Exhibit 6

### REGIONAL FUEL MIX AND EVOLUTION VARIES WIDELY TO 2020 DEPENDING ON INDUSTRY PROFILE AND ENERGY ENDOWMENT

**Fuel mix of industrial final-energy demand* by region, 2003–2020**
QBTU, %



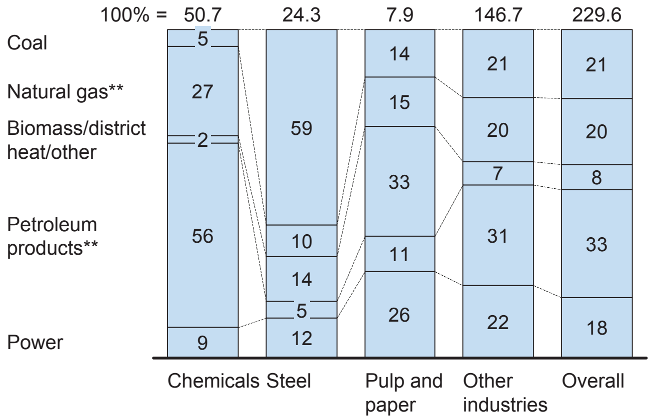

* Final energy demand does not include transformation losses as end-user energy demand does.
** The natural-gas category includes only methane; ethane is included in the petroleum-products category.
Source: MGI Global Energy Demand Model

Each industrial segment's unique need for a particular combination of feedstocks leads to widely differing fuel shares. Natural gas and petroleum products fulfill around 80 percent of chemical industry needs in 2003 and 2020, while coal provides 60 percent of the energy required by the global steel industry, and biomass and other energies fulfill one-third of pulp and paper energy needs (Exhibit 7).

**Exhibit 7**

**INDUSTRIAL SEGMENTS CONTINUE TO HAVE VERY DIFFERENT FUEL MIXES TO 2020**

**Fuel mix of industrial final energy demand* by segment, 2003–2020**
QBTU, %




* Final energy demand does not include transformation losses as end-user energy demand does.
** The natural-gas category includes only methane; ethane is included in the petroleum-products category.
Source: MGI Global Energy Demand Model

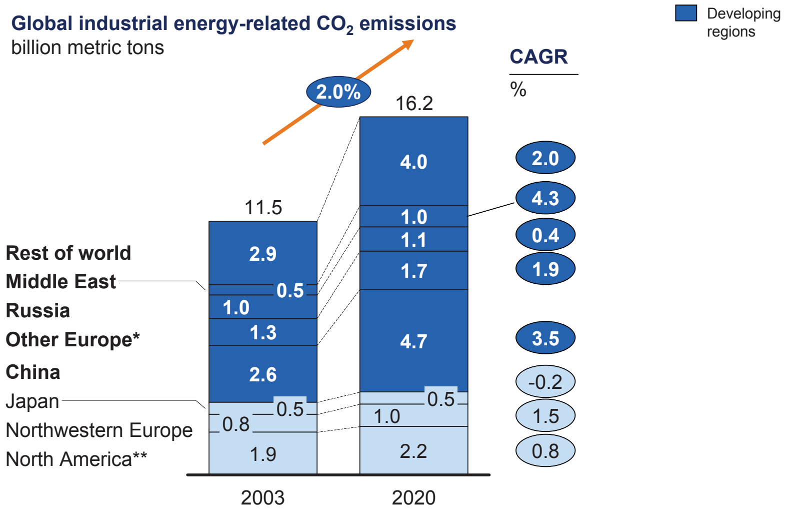
## $CO_2$ emissions growth by region

Industrial energy-related $CO_2$ emissions will grow from 11.5 gigatons in 2003 to 16.2 gigatons by 2020—a 2.0 percent CAGR. However, industry will actually see its share of overall $CO_2$ emissions decline from 49 percent to 46 percent by 2020 as consumer-driven segments grow more rapidly. In 2020 the chemicals and steel sectors will emit 2.5 and 2.2 gigatons of $CO_2$ respectively. When combined, their emissions represent 13 percent of the global total—equivalent to some 70 percent of all road-transport emissions and just below 65 percent of all residential emissions.

China's share of total global industrial emissions grows from 22 percent to 29 percent—with emissions reaching 2.4 times those of the United States by 2020. In fact, by 2020, China's industrial sector will contribute over 13 percent of global energy-related $CO_2$ emissions, with 4.7 gigatons of $CO_2$. Industrial emissions in the United States will grow from 1.7 to 2.0 gigatons—a 0.7 percent CAGR—and Europe will grow from 2.0 to 2.7 gigatons—a 1.7 percent CAGR—with the developing regions of Europe driving this growth (Exhibit 8).

## Exhibit 8

GLOBAL INDUSTRIAL $CO_2$ EMISSIONS WILL GROW BY 2.0% A YEAR TO 2020, WITH CHINA AND MIDDLE EAST POSTING THE STRONGEST RISE




* Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.
** US and Canada.
Source: IEA; MGI Global Energy Demand Model

## III. DRIVERS OF ENERGY DEMAND

### Case-study methodology and sources

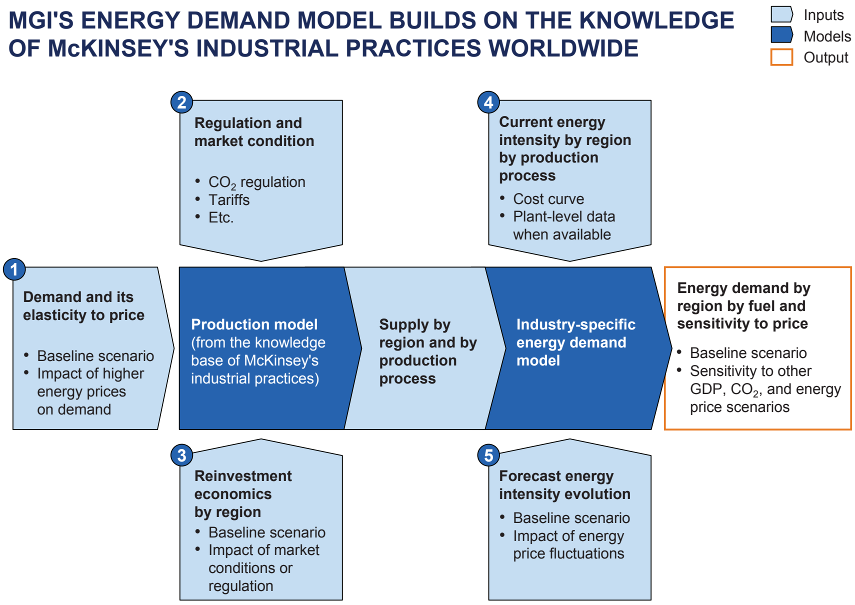
We base our industrial energy demand forecasts mainly on a detailed microeconomic analysis of a selection of major industries. We then complement this with macroeconomic forecasts for fragmented industries that were too small to warrant such a detailed level of scrutiny.

Our methodology builds on the work of McKinsey's industrial practices, whose deep understanding of the sector dynamics around the globe helps us to build an energy demand perspective from the ground up (Exhibit 9). For each industrial product covered, we first determine the likely volume of production by region and by segment. We do this by analyzing demand and its elasticity to price, the regulatory and market environment, and reinvestment economics.[1] Second, we model the energy intensity of each industry, which we define as the energy consumed per physical unit of output produced. Future energy intensity is driven mainly by the evolution of two factors: the mix of production processes, and energy efficiency. We analyze efficiency by looking both at the installed production base and its projected upgrades, and at the efficiency of new plants and the replacement of old plants by new, more efficient installations.

1 Reinvestment economics play a key role in determining the amount of new production capacity likely to be built in the future. The key parameters of reinvestment economics are the initial investment amount, and the cash costs per unit of capacity of operating a new facility.

## Exhibit 9

MGI'S ENERGY DEMAND MODEL BUILDS ON THE KNOWLEDGE OF McKINSEY'S INDUSTRIAL PRACTICES WORLDWIDE




Source: MGI analysis

We then produce our overall forecasts for energy demand at the level of each industry segment by aggregating our production forecast and our projection of energy intensity per unit produced.

### Industry-level case studies

We analyzed in detail a selection of energy-intensive industries, each of which will see a significantly different pattern of energy demand in the future. Accurate energy demand forecasts could not have been built solely on the observation of these sectors' historical demand trajectories; we had to conduct a deep analysis of the dynamics currently at play.

We present in-depth case studies on three major industrial end users: select petrochemical segments (ethylene and its derived products, nitrogenous fertilizers, and chlorine-caustic), steel, and pulp and paper. We chose these because of the size of their energy demand—they cover 31 percent of global industrial energy demand, and close to 50 percent of the growth we project in our base-case scenario to 2020.

### Approach for remaining demand

For those industries that we did not study in depth, we projected energy demand based on their historical evolution. For each region and industry, we determined the historical multiplier between growth in the industry's output and in its energy demand, using data from the past 10 years. In most cases, there was a strong correlation between an industry's energy consumption and its output, and we therefore used our output projections by sector to estimate the evolution of energy demand. In cases where this relationship was either not convincing or not intuitive, we applied average historical annual growth to build our projections.

We consider this methodology reasonably solid for those industries to which we applied it—i.e. smaller and relatively fragmented energy-consuming segments. As these industries are not large energy consumers, it is very unlikely that dynamics arising from energy markets (e.g. price and the availability of supply) will materially affect their evolution. In addition, because of their large number and diversity, it is unlikely that these segments will together digress from their historical evolution path, unless significantly affected by varying GDP growth rates.

**Global and local demand**

The first major factor determining the growth of industrial-sector energy demand to 2020 is the trend in demand for industrial products. However, at country-level the real driver is not demand but production. Demand and production will be close to equal only if imports and exports are in balance. Production forecasts are therefore the first component in our energy demand projections.

From the production-location standpoint, industries can be broken into two categories: global and local. For global industries, such as aluminum, ammonia, and some flat-steel segments, shipping costs are small compared with the cost differential among regions, and the development of export-based capacity in low-cost countries makes economic sense. For local industries, such as food processing, cement manufacturing, or chlorine production, long-distance shipping costs are higher than production-cost differentials. Other factors, such as regulation (e.g. tariffs, or restrictions on shipping of hazardous materials) and the availability of raw materials, also influence the characteristics of an industry. Our analysis found that approximately one-half of global industrial energy demand comes from global industries and one-half from local industries in 2003 (Exhibit 10).

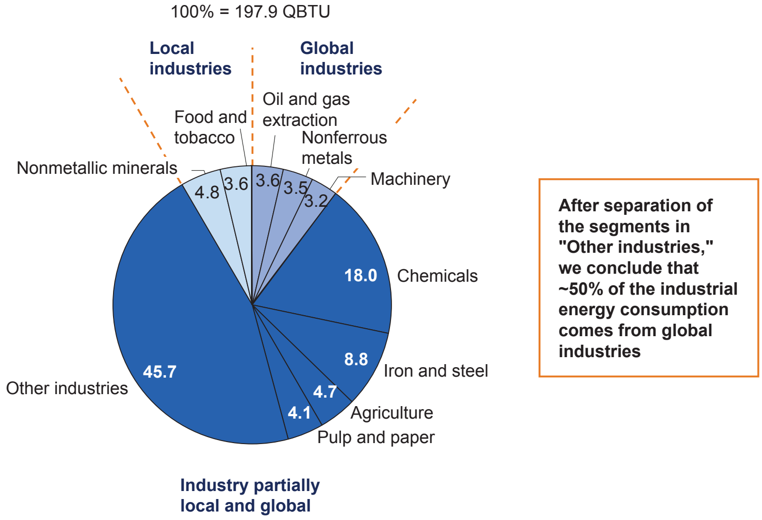
Our projections show that global production volumes will grow at about the same rate as GDP across several industries—by around 3 percent in steel, pulp and paper, and nitrogenous fertilizers. Ethylene, the largest single chemicals segment, will grow at 4.3 percent per year.

Our base-case projections indicate a slow shift in the proportion of industrial production conducted in developed regions toward developing regions, for example from the United States and the United Kingdom to India and China. This is caused by faster growth of industrial demand in these regions, as well as the evolution of local industry mixes. Relocation of industries also plays a role, but the impact is much smaller (Exhibit 11). The Middle East grows at approximately 6 percent per year in steel and chemicals, driven by strong growth of 10 percent in ethylene and fertilizer production. Increased production for exports helps drive these high growth rates. Chinese production of steel and ethylene grows at approximately 7 percent per year. India's steel and ethylene industries show similar growth rates to those we expect in China, albeit starting from a lower base. Production in both China and India focuses primarily on meeting domestic demand.

**Exhibit 10**

**GLOBAL END-USER INDUSTRIAL ENERGY DEMAND IS SPLIT EQUALLY BETWEEN GLOBAL AND LOCAL INDUSTRIES**

%




Source: IEA; MGI analysis

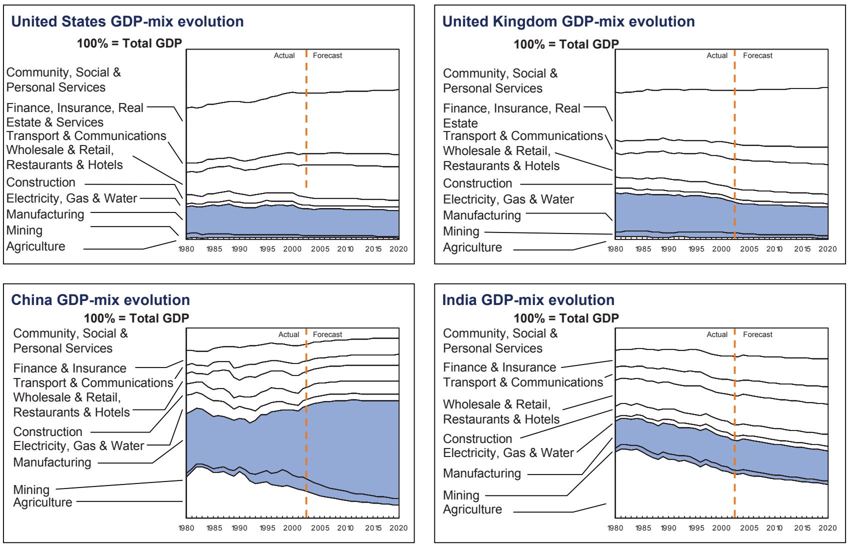
In contrast, industrial-output growth remains moderate in developed regions as they experience a continued shift toward services. For instance, steel production in developed regions decreases by 1 percent per annum to 2020, while paper production grows only at about 1 percent per year, and ethylene production at under 2 percent per year. Meanwhile, nitrogenous fertilizer production will be flat in Japan, will decrease slightly in developed Europe, and will continue to decline at 1 percent per year in the United States. These demand and production-location shifts result in significantly different industrial energy demand growth at the regional level.

**Fuel mix**

Switching among fuels can have a significant impact on the global energy balance. However, we forecast no major changes in the fuel mix of the industrial sector at the global level. We see only a small shift in the share from electricity and natural gas to coal and petroleum products, most of which is explained by a change in the industry and regional mix of demand.

**Exhibit 11**

**SHARE OF INDUSTRIAL ENERGY PRODUCTION SHIFTS GRADUALLY FROM DEVELOPED TO DEVELOPING REGIONS (1980–2020)**




Source: Global Insight; MGI analysis

Our analysis focuses more on long-term switching mechanisms, because they are the main drivers of that small shift in fuel mix which we do see in the industrial sector to 2020. We project limited short-term fuel switching. This process typically happens in two ways. First, relatively few plants are capable of switching from one energy source to another. They are mainly the large chemical plants, which use various feedstocks to produce similar end products. But switching can also occur in those smaller energy-consuming industries that do not require a high level of heat. However, we see no evidence that many more facilities will develop fuel-switching capabilities in the future given the high investment required. Second, industries with overcapacity can switch between idle and operating plants depending on the type of energy those plants use. However, this happens only in highly energy-intensive industries, where a relative movement in fuel prices can reorganize the cost curve, and thus alter the production economics among plants.

In the longer term, fuel switching is generally caused by a change in the mix of industrial activity, or a shift between production processes within industrial sectors. The shift in industry mix, and even "subindustry mix," is the most important factor at work. For instance, our projection that coal will gain share of the global industrial fuel mix is determined by fast growth of coal-intensive industries such as steel (primary steelmaking uses coal as a predominant fuel) and the generalized expansion of all industries in coal-rich China. In the same way, strong projected increase in demand for petroleum products will be driven by solid growth in the petrochemical industry, especially in ethylene—an intensive end user of petroleum products—and by fast overall growth in the petroleum-intensive Middle East.

A shift in capital stock within a particular industrial segment can also prompt a fuel-mix change. Although there are few available examples of this, the steel industry is a case in point. A relative shortage of scrap over the next 10 years will result in more integrated steelmaking, rather than manufacture by means of electric arc furnaces (EAF). This will cause a small shift from electricity to coal consumption.

**Energy intensity**

The final factor influencing industrial energy demand is the trend in the energy intensity of the various production processes. Within each sector, energy intensity is determined by both the mix of production processes and the level of energy efficiency. Two elements affect an industry's energy-efficiency evolution: first, efficiency improvements at existing plants; second, superior efficiency of new plants and the replacement of old plants by newer, more energy-efficient plants.

Typically, the two key drivers of the energy intensity of existing plants are energy prices and the hurdle rates employed to evaluate plant-level capital investment. McKinsey's past experience with industrial clients suggests that hurdle rates for these types of projects are generally very high. Many corporations require a payback period of just two to five years for such an investment (sometimes even less), which is equivalent to a discount rate of more than 20 percent. This reflects the broad range of risks that plant-level investments face, including volatility of both energy and output prices, and the utilization of the capacity in specific plants under different market scenarios. Greater predictability in energy prices, a more stable economic environment, and lower interest rates could lower the hurdle rates, and significantly reduce industrial energy intensity.

Another aspect of energy intensity—capital stock turnover—is generally predictable. New plants are typically built with technology that is the most economical on a long-term basis, and there is some "creep" in the energy-efficiency levels of new capital stock. Furthermore, in several sectors different production processes are available which offer sharp differences in energy intensity. For example, certain steel grades can be produced using basic oxygen furnaces (BOF) or using scrap metal in an EAF. The latter process uses only one-third of the energy although, of course, it relies on the availability of scrap.

Our projections for the energy intensity of each industry are derived by combining the projected mix of production processes with projected efficiency improvements within current plants and capital replacement. In the steel sector, we project cumulative process type efficiency improvements of 4–11 percent, with greater improvements in developing regions as they install larger-scale capacity and hence benefit from scale economies. This efficiency gain is offset by the shift toward more energy-intensive BOF and EAF-DRI production, capping the growth in less energy-intensive steel production using scrap, as scrap supply will grow only slowly to 2015. As a result, global steel energy intensity remains virtually unchanged to 2020.

Furthermore, we project very little change in chemicals energy intensity to 2020. This is due to the feedstock-intensive nature of many chemicals segments; there is a technical limit to converting energy feedstock into products. Chlorine production will be an exception because the retirement of environmentally detrimental mercury-cell capacity will also reduce energy intensity. Mercury-cell plants are 25 percent more energy intensive than newer membrane technology. This should not be overemphasized, however, as chlorine production represents only 3–4 percent of chemicals energy demand, and mercury-cell plants currently hold only a 15 percent share.

### CASE STUDY A—SELECTED PETROCHEMICAL SEGMENTS

Energy demand from the chemical industry is forecast to grow at a compounded annual growth rate of 3.1 percent to 2020. This relatively high rate is due both to strong organic growth and to continuing substitution of chemicals (mainly plastics) for other materials (e.g. natural fibers, metal, glass).

Chemical plants are best situated either close to the site of final demand for chemicals, or close to abundant sources of relevant feedstocks. Therefore we forecast that most of the growth in energy demand from the chemical industry will occur in Asia (with China growing at 5.7 percent per year) and in the Middle East (growing at 6.2 percent per year).

The petrochemical industry is by far the most energy-intensive industry in the world. With a large number of end products and an even greater variety of end uses, this industry needs to be broken down into its various segments in order to understand the evolution of its future energy demand. Our analysis focuses on the three largest, most energy-intensive segments[2]: ethylene (including its by-prod-

2 For the purposes of our analysis we consider the large refining industry as a transformation sector that grows with demand for its energy products—mainly transportation fuel and chemical feedstock.

ucts and derived products); nitrogenous fertilizers; and chlorine-caustic (Exhibit 12). Indeed, ethylene, ammonia, and chlorine account for more than 40 percent of energy demand from the chemical industry (Exhibit 13). We then use findings on these segments to extrapolate projections for other, smaller segments.

**Exhibit 12**

## MGI EXAMINED IN DETAIL THREE PETROCHEMICAL SEGMENTS AND THEIR PROJECTED EVOLUTION

Detailed analysis

| | Worldwide energy demand, 2003<br>QBTU | Key driver of demand evolution | Uncertainty of energy demand evolution |
|---|---|---|---|
| Ethylene | 5.5 | • Relocation to stranded-gas and high-growth regions<br>• Coal gasification technologies | |
| Ammonia | 7.3 | • Relocation of capacity to stranded-gas regions<br>• Coal gasification technologies | |
| Chlorine | 1.5 | • Conversion to membrane technology | |
| Other chemicals | 21.3 | • GDP growth | |
| **Total** | **35.6** | | |

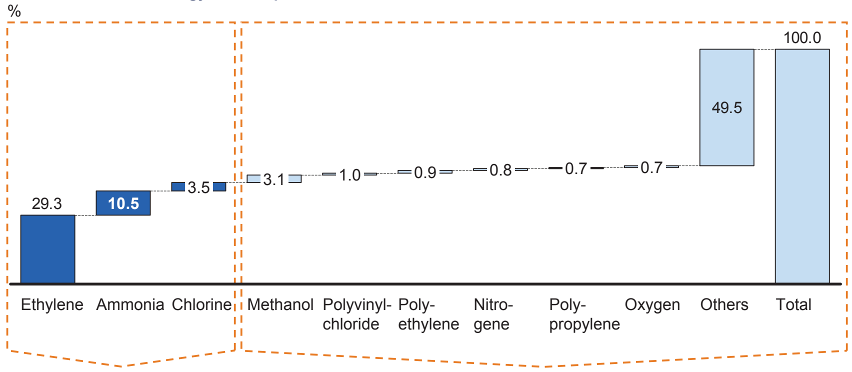
Source: MGI analysis

**Exhibit 13**

## ETHYLENE, AMMONIA, AND CHLORINE ACCOUNT FOR MORE THAN 40% OF CHEMICAL INDUSTRY ENERGY DEMAND

Detailed analysis

**Estimated US final energy consumption* for selected chemicals**
%




**Energy prices play a significant role in the economics of these products; main focus of our detailed analyses**

Energy prices play a marginal role in the economics of these products and are unlikely to reshape the related industries; industry evolution is assumed to be mainly GDP-driven

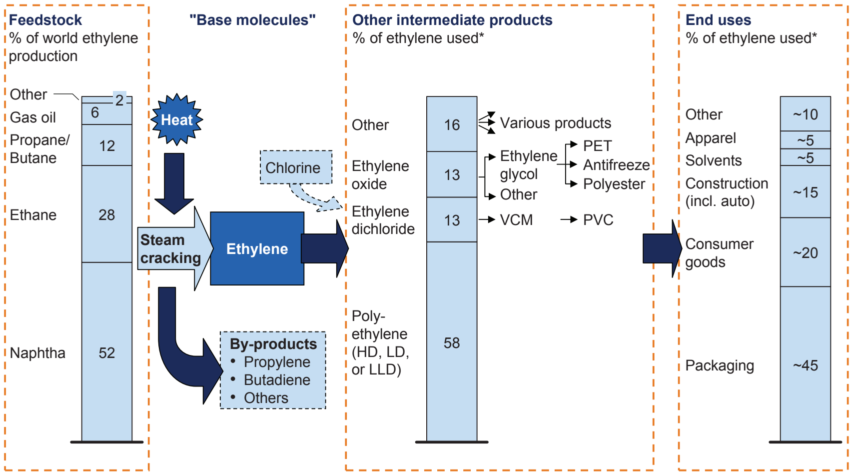
* Including feedstock based on 1994 data.
Source: Warrell et al (2000); MGI analysis

## ETHYLENE

Ethylene is an organic chemical in the middle of a highly complex value chain that begins with its raw materials, and includes a large number of intermediate products with a wide range of end uses (Exhibit 14).

**Exhibit 14**

### ETHYLENE IS AT THE CENTER OF A COMPLEX VALUE CHAIN



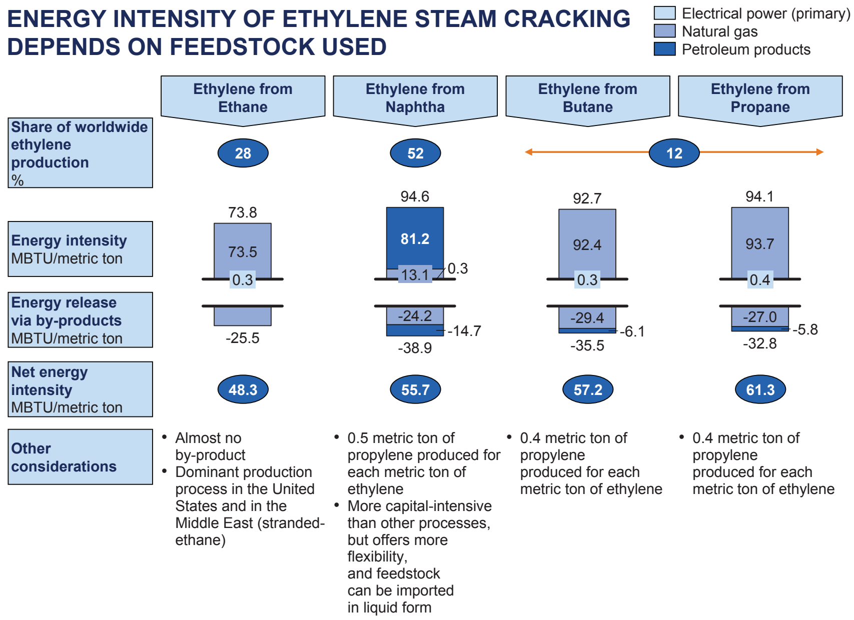

* North America only.
Source: Warrell et al (2000); TIG; MGI analysis

**How ethylene is made**

Ethylene is typically produced by the steam cracking of a petrochemical feedstock (e.g. naphtha, ethane, propane, butane). This process requires an energy input as heat (the energy that is burned or consumed), and an energy input as a feedstock (the product that serves as a raw material). The energy intensity of the ethylene-making process depends mainly on the type of feedstock used (Exhibit 15).

The cracking of a light feedstock such as ethane results in few co-products, and is less energy intensive than the cracking of a heavier feedstock such as naphtha or propane, even after allocating energy input to the respective co-products. However, the choice of a feedstock is rarely driven solely by the energy intensity of the process. Existing production capacity (some plants can process multiple feedstock types; others cannot), feedstock availability, and demand for co-products all play a much more important role in determining the mix of feedstocks employed in a given region. So energy intensity is not a major consideration in the choice of production process.

**Exhibit 15**




Source: SRI Consulting; MGI analysis

More than 99 percent of global ethylene production currently derives from steam cracking. Other production processes such as coal gasification and catalytic dehydration can be used, but their penetration is currently marginal. We project that steam-cracking technology will still be deployed in well over 95 percent of new ethylene plants to be built over the next five years (Exhibit 16). However, in the long term, we could see significant growth of methanol-to-olefins processes using low-cost methanol or coal, especially in China.

Ethylene is used to produce a variety of subproducts, such as polyethylene, ethylene dichloride, and ethylene oxide, which, in turn, are used in a number of end-use sectors, such as packaging, consumer goods, solvents, and apparel (Exhibit 17).

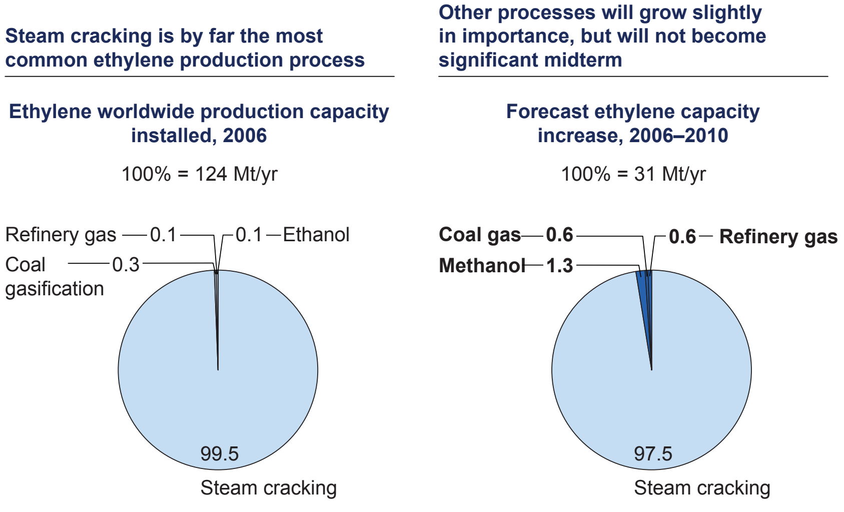
### Ethylene demand and elasticity

Ethylene demand has historically grown at a faster rate than the global economy as a whole, not only because it is relevant to a large number of end-use segments, but also because, over time, it tends to replace other materials in a number of applications (e.g. packaging, appliances, construction).

Developing regions still present substantial opportunities for the penetration of ethylene-based products. Because of this, together with an established global

## Exhibit 16

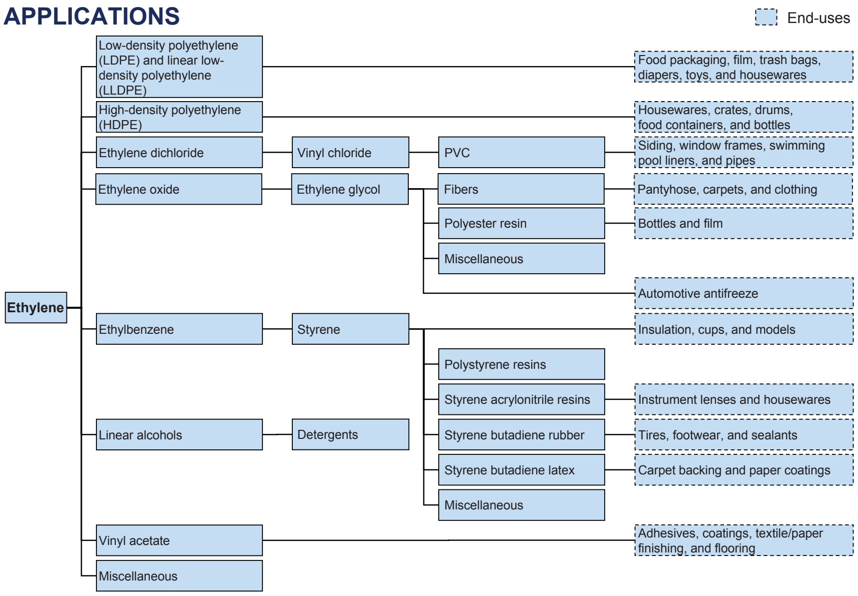
### STEAM CRACKING WILL REMAIN THE MOST COMMON PRODUCTION PROCESS FOR ETHYLENE




Source: Tecnon; MGI analysis

## Exhibit 17

### SUBPRODUCTS OF ETHYLENE ARE USED IN A WIDE RANGE OF APPLICATIONS

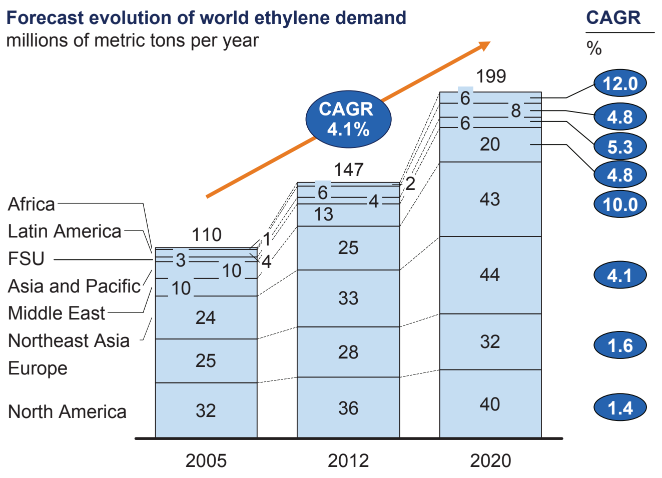



Source: American Chemistry Council

trend of substituting metal, glass, and paper products with ethylene-based resins, we forecast that global demand will continue growing at a rate of 4.1 percent per annum (Exhibit 18).

**Exhibit 18**

**GLOBAL ETHYLENE DEMAND IS EXPECTED TO GROW AT 4.1% A YEAR TO 2020**




Source: Tecnon; MGI analysis

Examples of substitution are numerous. For instance, ethylene competes with aluminum, glass, and paper in packaging, and with steel and aluminum in some consumer-goods applications. Given this widespread substitutability of ethylene-based products, one might expect a high level of demand elasticity to price. However, historical price and demand data show very little evidence of such elasticity (Exhibit 19). A closer analysis of substitution trends shows that, in almost every case, a move toward ethylene-based resins is permanent. The massive capital investments needed to enable the use of a different material make short-term substitution based on price prohibitive.

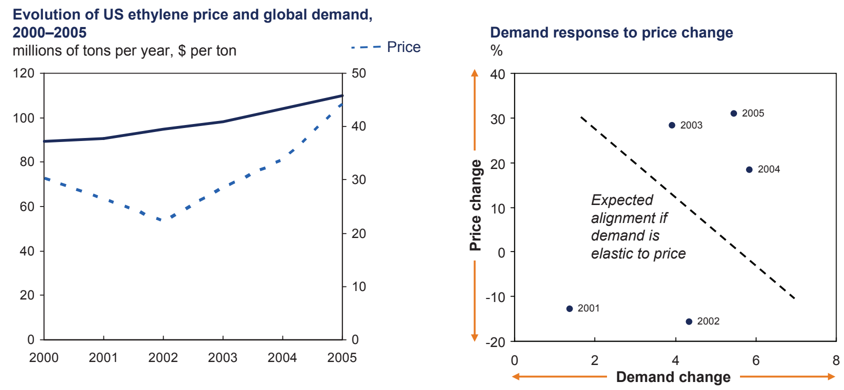
We therefore project that ethylene demand will follow global economic growth, at a slightly faster pace, and that energy prices will have very little impact on the evolution of demand. We foresee no major shocks or disruption to the market or regulatory environment that would impact demand for ethylene.

### Reinvestment economics

New production capacity will be located in regions where demand grows most quickly—notably, in China. Production may also locate where stranded feedstocks are available, such as stranded ethane in the Middle East. Interregional trade of ethylene is very small (Exhibit 20); this does not mean that ethylene is not a global commodity—rather that interregional exchange happens at another level of the value chain. Trade takes place either at the very start of the value chain (i.e. the import of feedstocks to regions where end-user demand for ethylene-based products is strong), or toward the end of it (i.e. the export of polyethylene sheets from countries that have access to cheap feedstocks).

**Exhibit 19**

**PRICE DOES NOT APPEAR TO HAVE A SIGNIFICANT INFLUENCE ON ETHYLENE DEMAND**




- Although some elasticity through material substitution is observed at the margin in some applications (polyester to cotton in China, PET bottles to aluminum cans), overall demand for ethylene does not seem elastic to price
- Uses of ethylene are very diverse, and elasticity in one of the end uses is unlikely to make a significant difference to overall demand

Source: Chemical Market Associates Inc. (CMAI); Tecnon; MGI analysis

**Energy intensity**

Energy for the ethylene production process comes from both the feedstock and the heat input. The direct chemical relationship between the volume of ethylene produced and the volume of feedstock needed means that no change in the energy intensity of the process can be expected. With regard to the heat input, a theoretical minimum amount of heat is needed to obtain ethylene from a given feedstock. All plants use more than this theoretical minimum but, since the technology is well established and the difference between the theoretical minimum and the actual energy consumption is relatively small, we do not expect significant reductions in energy intensity in the future.

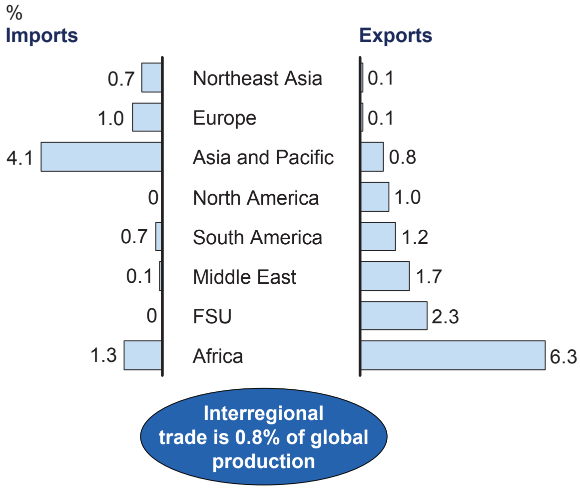
## NITROGENOUS FERTILIZERS

More than 80 percent of worldwide ammonia and its derivatives is used in fertilizers, with the remaining share being used in various other applications such as explosives, nylon fibers, and acrylic fibers (Exhibit 21).

## Exhibit 20

### ETHYLENE TRADE VOLUMES ARE SMALL

Ethylene interregional trade as a proportion of local production

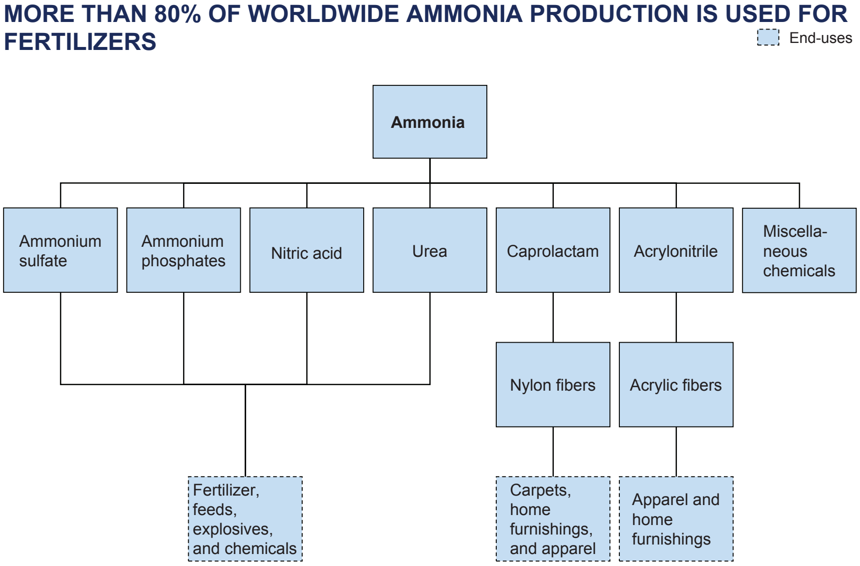



- **Interregional trade of ethylene is small, and likely to remain so**
- **New capacity is being built in the Middle East and in Asia, but products exported are further downstream (polymers for the Middle East, finished products for Asia)**

Source: Tecnon; MGI analysis

## Exhibit 21

### MORE THAN 80% OF WORLDWIDE AMMONIA PRODUCTION IS USED FOR FERTILIZERS



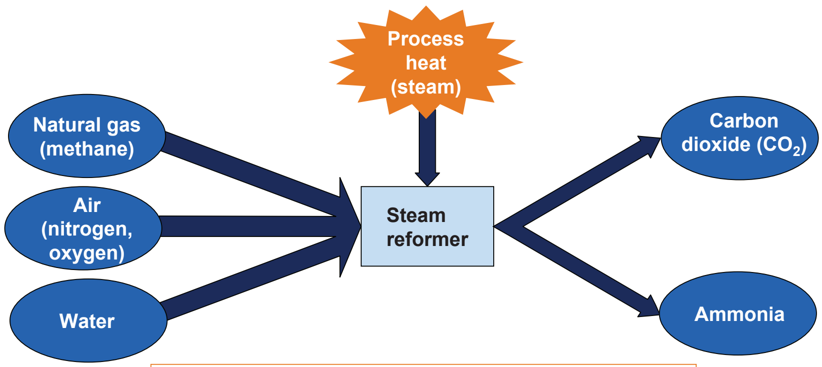

Source: American Chemistry Council

### How ammonia is made

The most common process for producing ammonia is the steam reforming of natural gas (Exhibit 22). Under a high temperature, natural gas (mostly methane) reacts with oxygen and nitrogen from the air to produce ammonia (a gas at normal pressure and temperature) and to reject carbon dioxide ($CO_2$). Steam reforming can also utilize heavier feedstocks such as ethane, propane, and naphtha.

**Exhibit 22**

**STEAM REFORMING OF NATURAL GAS IS THE MOST COMMON AMMONIA PRODUCTION PROCESS**



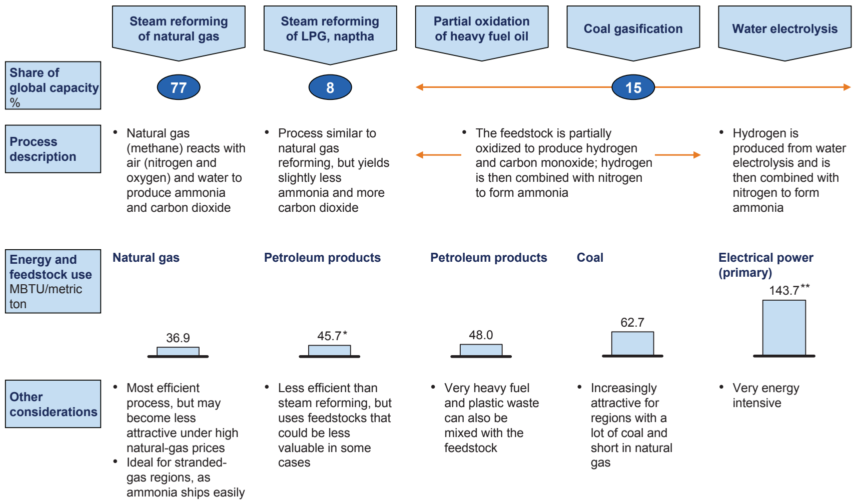

| Physical and thermodynamic minimum energy needed | |
|---|---|
| Energy input | 5.5 MBTU/t |
| Feedstock (0.41t methane) | 21.9 MBTU/t |
| **Total** | **27.4 MBTU/t** |

Source: European Fertilizer Manufacturers Association (EFMA); MGI analysis

Other production processes are also used to produce ammonia from heavy fuel (through partial oxidation), from coal (through coal gasification), and from water (through electrolysis). However, these other processes account for only 15 percent of production, with steam reforming accounting for the rest. The various processes have different characteristics, including energy intensity (Exhibit 23).

**Exhibit 23**

## AMMONIA PRODUCTION METHODS VARY IN ENERGY INTENSITY




* Estimate; assumes the use of propane and the same efficiency as natural gas reforming (compared to technical frontier).

** Estimate; includes electricity generation losses (assumes 33% efficiency).

Source: EFMA; United States Geological Survey; MGI analysis

### Ammonia demand and elasticity

Ammonia demand shows a steady upward trend as developing regions continue to adopt chemical fertilizers. We expect demand to continue at its historical pace, driven mainly by economic growth, which makes ammonia more affordable for developing regions, and by global population growth, which increases demand for agricultural output. Announced capacity expansion is strongest in the Middle East and Asia, particularly in China (Exhibit 24).

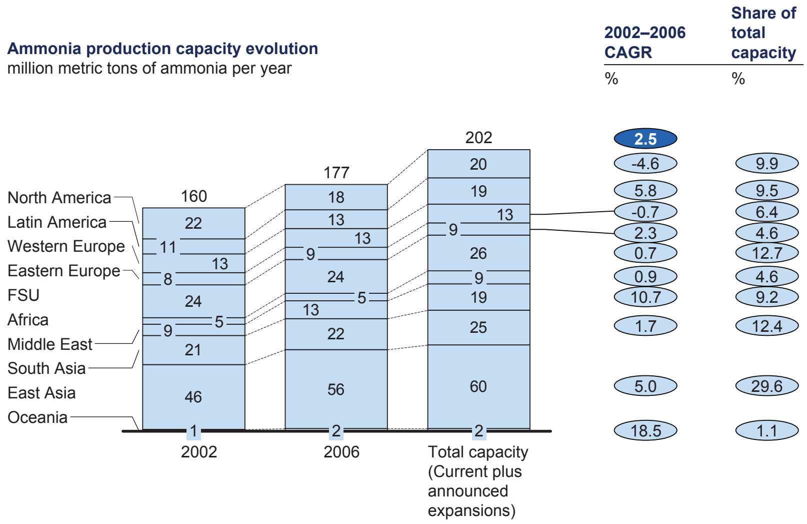
There is little evidence of ammonia demand being elastic to price, with demand fluctuations, especially in developed regions, driven much more by weather conditions. (Given that the product is used mainly as a fertilizer, its efficiency is highly dependent on the amount of precipitation.) Therefore, although the variable production costs for ammonia are closely related to energy prices (Exhibit 25), we expect to see no significant changes in demand for nitrogenous fertilizers under various energy-price scenarios.

### Reinvestment economics

The ammonia industry has already seen a massive shift in location, mainly from North America which experienced an increase in natural-gas prices, to countries enjoying significant supplies of stranded natural gas. As variable production costs depend very heavily on gas prices, there is a strong economic incentive for

## Exhibit 24

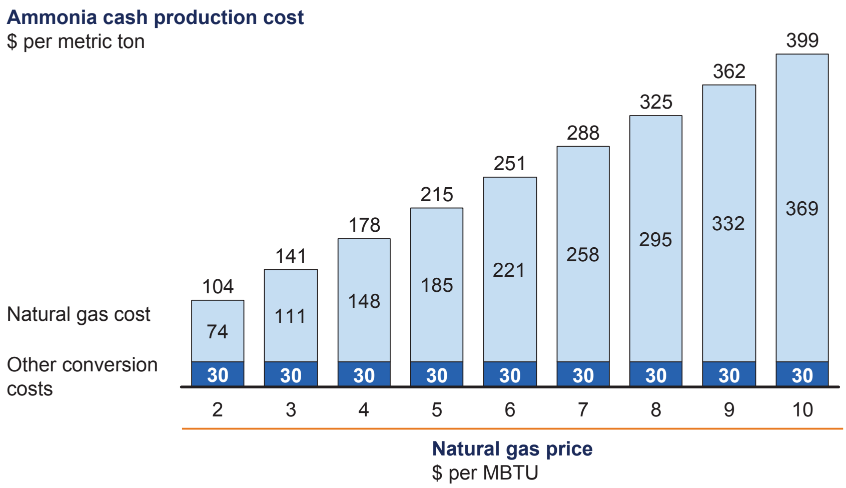
### AMMONIA PRODUCTION CAPACITY EXPANDING MOST QUICKLY IN THE MIDDLE EAST AND EAST ASIA




Source: IFDC; MGI analysis

## Exhibit 25

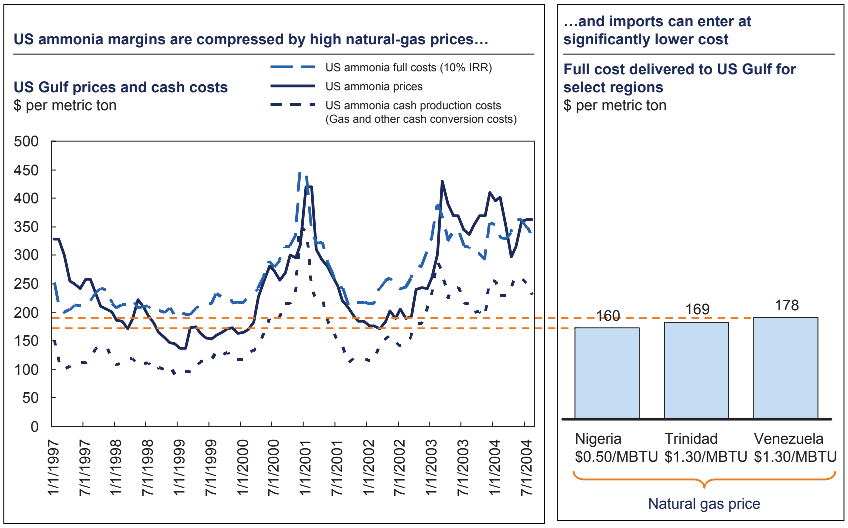
### AMMONIA PRODUCTION COST IS HIGHLY DEPENDENT ON THE COST OF FEEDSTOCK




Source: United States Geological Survey; MGI analysis producers to install capacity in regions where natural gas is cheap. Over the past 10 years, there were long periods during which the variable cost of producing ammonia in the United States was higher than the full cost of producing ammonia in a new plant in a region with low gas costs and then delivered to the United States (Exhibit 26).

**Exhibit 26**

HIGH US NATURAL-GAS PRICES HAVE CONTRIBUTED TO SOME RELOCATION OF CAPACITY IN LOW-COST GAS REGIONS




Source: Green Markets; Platts; MGI analysis

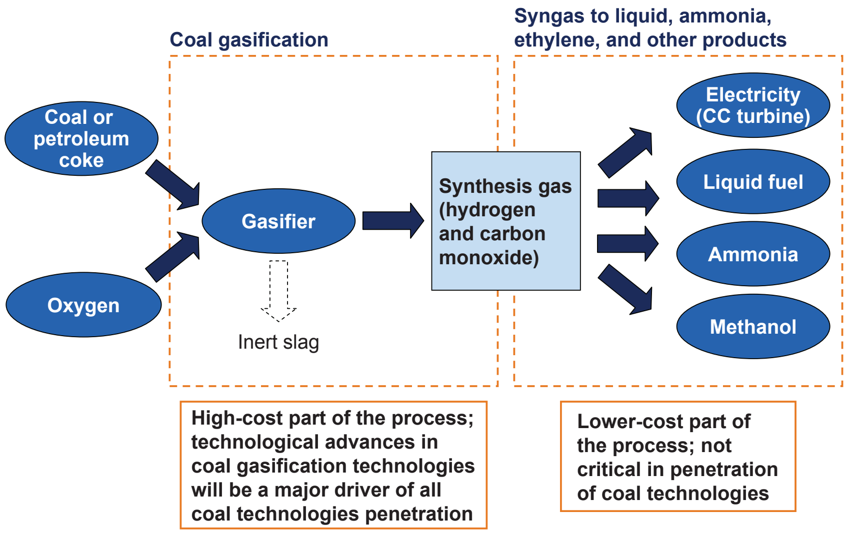
This wave of relocation now appears to have run its course, and we expect new capacity to be installed in low-gas-cost regions. However, at the same time, we anticipate that existing capacity in high-gas-cost regions will remain in place. Those plants that have survived the latest phase of relocation are likely to have done so because they were harder to move—maybe because they are farther from the coast, or are less exposed to direct competition from imports, or are processing end products which are harder to ship, such as anhydrous ammonia. Given that the development of a global liquefied natural-gas market is effectively putting a cap on interregional price differences, it is unlikely that the remaining capacity in the United States will be displaced.

**Coal gasification: increasingly used for ammonia plants in China**

The production of ammonia through coal gasification involves two steps (Exhibit 27). The actual "gasification" tales place in the first step, when coal is burned in an environment low in oxygen. This reaction produces a synthesis gas which is a mix of hydrogen and carbon monoxide. In the second step, the synthesis gas can be used to produce petrochemical products, liquid fuels, or even electricity. A combination of processes is sometimes used in order to increase the plant's flexibility (Exhibit 28). When used to produce ammonia, the synthesis gas is combined with nitrogen (from ambient air) in a reformer in a process similar to that used to produce ammonia from natural gas.

**Exhibit 27**

### COAL GASIFICATION CONSISTS OF A TWO-STEP PROCESS



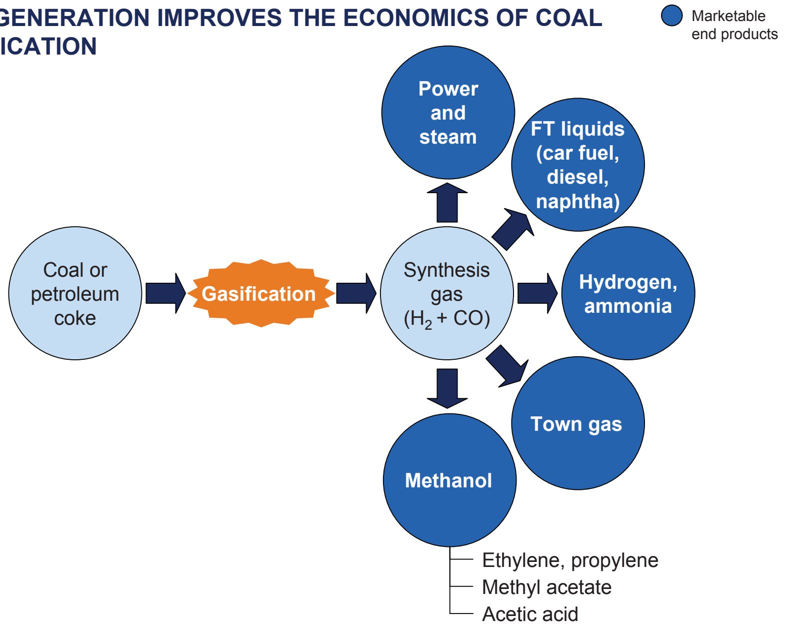

Source: US DOE; MGI analysis

Processes that turn coal into gaseous or liquid fuels have been around for a long time, but historically the prices of natural gas and petroleum products have never been sufficiently high to make them economically viable in the long term. For this reason, in the past this technology was limited to specific situations where other fuels were not readily available (Exhibit 29). However, developments in technology and higher energy prices are likely to result in increased use of coal gasification in future.

China has long used this technology in small-scale ammonia plants, and is now one of the most likely prospects for an expansion of coal gasification, given the widespread availability of coal and the country's reliance on imports of other fossil fuels. Moreover, with capital costs up to 40 percent lower than those in developed regions, China is a good candidate for this very capital-intensive technology. On top of this, a significant increase in fertilizer demand in China creates a perfect environment for new entrants. A number of large-scale coal-gasification projects have been announced over the past year, the majority being oriented toward the production of nitrogenous fertilizers (Exhibit 30).

## Exhibit 28

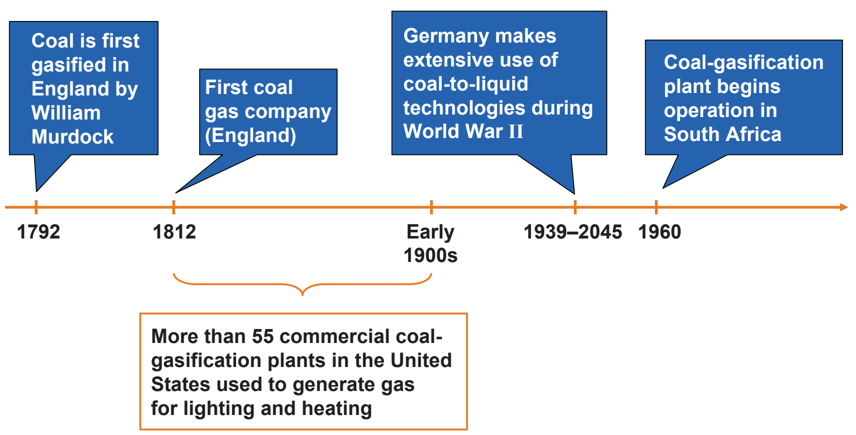
### POLYGENERATION IMPROVES THE ECONOMICS OF COAL GASIFICATION




Source: MGI analysis

## Exhibit 29

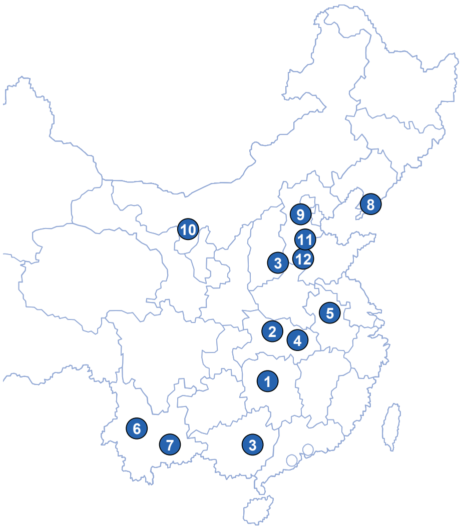
### COAL-GASIFICATION TECHNOLOGY HAS A LONG HISTORY




Source: US DOE; MGI analysis

## Exhibit 30

### A SIGNIFICANT NUMBER OF COAL GASIFICATION PROJECTS HAVE BEEN ANNOUNCED IN CHINA




1. Yueyang Sinopec and Shell Coal Gasification Co Ltd
   2,000 t/d plant to supply a fertilizer plant, 2001
2. Hubei Shuanghuan Chemical Group Co Ltd
   900 t/d plant to supply a fertilizer plant, 2001
3. Liuzhou Chemical Industry Co Ltd
   1,200 t/d plant to supply a fertilizer plant, 2001
4. Sinopec Hubei Chemical Fertilizer Co
   2,000 t/d plant to supply a fertilizer plant, 2003
5. Sinopec Anqing Chemical Fertilizer Co
   2,000 t/d plant to supply a fertilizer plant, 2003
6. Yunnan Tianan Chemical Co Ltd
   2,000 t/d plant to supply a fertilizer plant, 2003
7. Yunnan Zhanhua Co Ltd
   2,000 t/d plant to supply a fertilizer plant, 2003
8. Dahua Group Ltd
   1,000 t/d plant to supply a methanol plant, 2004
9. Yongcheng Coal and Power Group
   2,000 t/d plant to supply a methanol plant, 2004
10. Shenhua Coal Liquefaction Corporation
    2,000 t/d plant to supply $H_2$ for coal liquid, 2004
11. Zhongyuan Dahua Group
    1,800 t/d plant to supply methanol plant, 2004
12. Kaixiang Group
    1,000 t/d plant to supply methanol plant, 2004

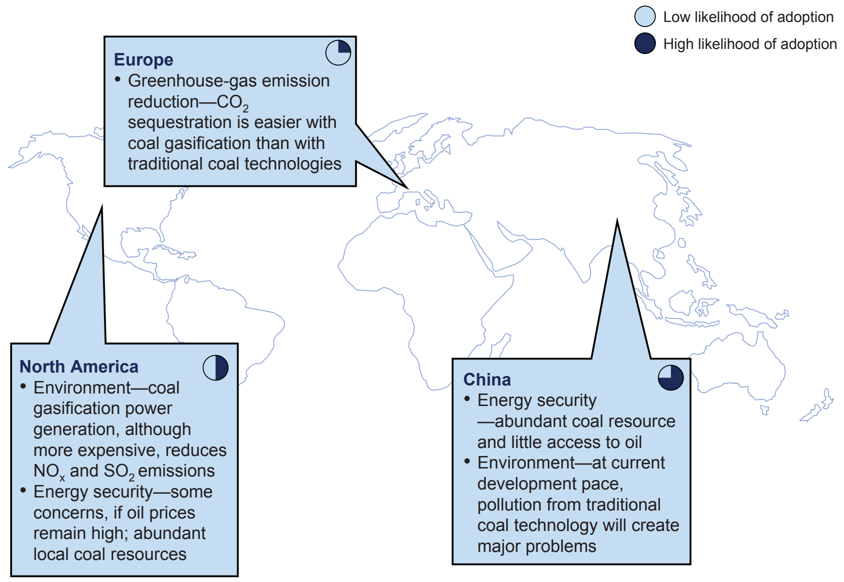
Source: Shell Gas and Power corporate presentation to gasification experts

Coal-gasification installations may also appear in other regions or for other end uses, but their economics are less certain. In the United States, the availability of coal, a political push toward energy security, and high natural-gas prices may create the conditions for some new coal-gasification capacity. In Europe, the technology's ability to lower the $CO_2$ emissions from coal may play in its favor (a process using coal gasification makes $CO_2$ sequestration easier than other more traditional processes using coal). On the other hand, access to relatively cheap natural gas and smaller coal reserves make the technology less attractive (Exhibit 31).

The future development of coal-gasification technology is still subject to major uncertainties (Exhibit 32). The price differential between coal and oil or gas drives its fundamental economics. In the future, regulatory uncertainty, in terms of both taxes on greenhouse-gas emissions and subsidies for alternative energy, may also significantly change the outlook for coal gasification. Last but not least, despite the fact that the technology has been around for many years, only a few large-scale plants are in operation globally, suggesting that there is potential for process improvement and capital-cost reduction if adoption rates pick up.

**Exhibit 31**

## THE RATIONALE FOR COAL GASIFICATION VARIES BY REGION




Source: MGI analysis

**Exhibit 32**

## COAL GASIFICATION WAS NOT COST-EFFECTIVE AT HISTORIC OIL PRICES, BUT THESE ECONOMICS MAY CHANGE RAPIDLY

| Factors influencing coal-gasification economics | Effect | Outlook for the future |
|---|---|---|
| • Oil and gas prices | • Higher oil and gas prices improve the economics of coal-to-liquids and coal-to-chemicals – exact breakeven point depends on many factors, but the technology is clearly economical at crude >$60 | • Forward crude curve suggests economics may remain favorable |
| • Environmental regulations | • More stringent regulations or higher emission costs favor IGCC over conventional coal power generation | • $SO_2$ and $NO_x$ emission norms expected to be further tightened, and current negotiations for a post-Kyoto GHG agreement |
| • Technology, scale | • Technology being relatively new, time and number of projects commissioned will contribute to both reduce capital costs and improve reliability | • Current forecasts are for IGCC technology to be fully competitive with conventional coal-fired power plant by 2020 |
| • Government incentives | • Incentives to clean-coal technologies directly contribute to improve coal-gasification economics | • US energy policy (2005) puts emphasis on coal gasification with the "clean coal power initiative" and credits for IGCCs |

Source: GE; Sasol; MGI analysis

### Energy intensity

As with ethylene production, the production of ammonia generally requires two sources of energy input—a feedstock and some heat. The amount of feedstock needed for each ton produced is fixed and will therefore remain stable in the future; the heat required can be reduced only close to a theoretical limit. As the distance between the heat actually used and this theoretical limit is small, we believe that there will be little change in the energy intensity of nitrogenous fertilizer production in the future.

The only significant changes in energy intensity will occur in developing regions. As in many other basic materials industries, energy productivity depends largely on scale and on the technology used. As large-scale, state-of-the-art facilities slowly replace small and inefficient plants, average energy efficiency will increase. Because it is almost impossible to analyze the efficiency of all the small plants in a country such as China (where scale is an issue in ammonia production), we assume that energy efficiency will improve at around its historical trend rate.

## CHLORINE AND CAUSTIC SODA

The chlorine-caustic segment differs significantly from the first two discussed. Chlorine-caustic is not an organic chemical—i.e. it does not require a petrochemical feedstock input—and its market dynamics are relatively local.

**How chlorine and caustic soda are made**

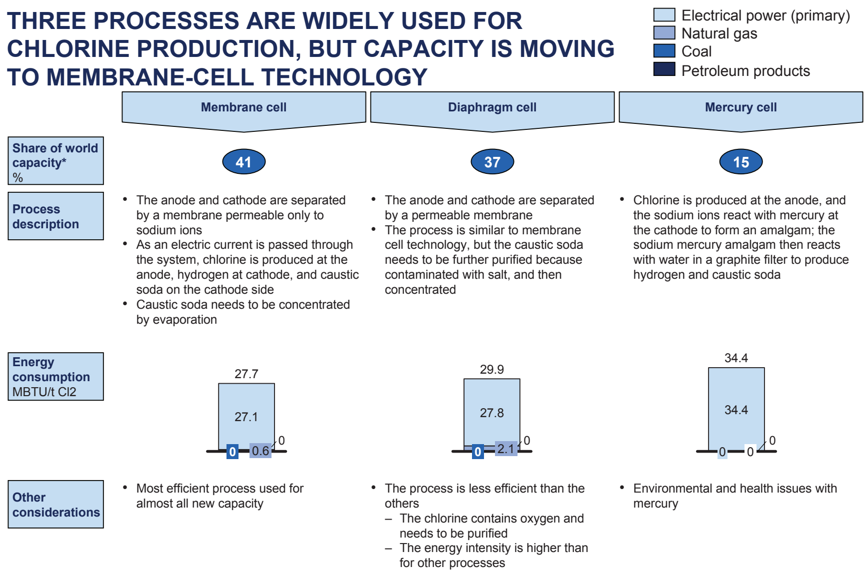
Chlorine and caustic soda are co-products of the same reaction. Three production processes are available: membrane cell, diaphragm cell, and mercury cell. In a membrane cell, chlorine and caustic soda are obtained through the electrolysis of a solution of water and sodium salt. The two electrodes are separated by a membrane that is permeable to sodium ions but not to chlorine ions. Gaseous chlorine forms at the anode (which is on the brine side); hydrogen forms at the cathode. The result is a solution rich in hydroxide (caustic soda).

The diaphragm cell works in a very similar way, except that the membrane is replaced by a diaphragm. The quality of the products is a little lower due to the greater permeability of the diaphragm, and the process is therefore slightly more energy intensive because the caustic solution needs to be purified of the salt it contains through evaporation. This older technology is still widely used, but the membrane process is usually preferred in new plants.

The last process employs the mercury cell, and is designed differently from the first two, despite the fact that it uses the same inputs (water, salt, electricity) to produce the same outputs (chlorine, caustic soda, hydrogen). In this process, chlorine is still recuperated in a gaseous state at the anode, but the sodium ions are fixed to a flow of mercury that acts as a cathode. Sodium ions are then separated from the mercury in a graphite catalyst to produce caustic soda, hydrogen, and mercury that is then recycled in the process. Because of the health risks related to mercury, this technology is no longer used for new capacity in developed regions, and existing plants are gradually being decommissioned. The pace at which they will be phased out will depend mainly on government regulation and incentive programs.

All three processes chiefly use electricity to power the electrolysis reaction, with other fuels being employed as heat only in order to further purify the outputs through evaporation. Of the three, the membrane-cell process is the least energy intensive, followed by the diaphragm cell and then the mercury cell (Exhibit 33).

**Exhibit 33**




* The three processes shown on this page cover 93% of the total chlorine production; most of the remaining 7% is produced using similar technologies with other salts (KCl).

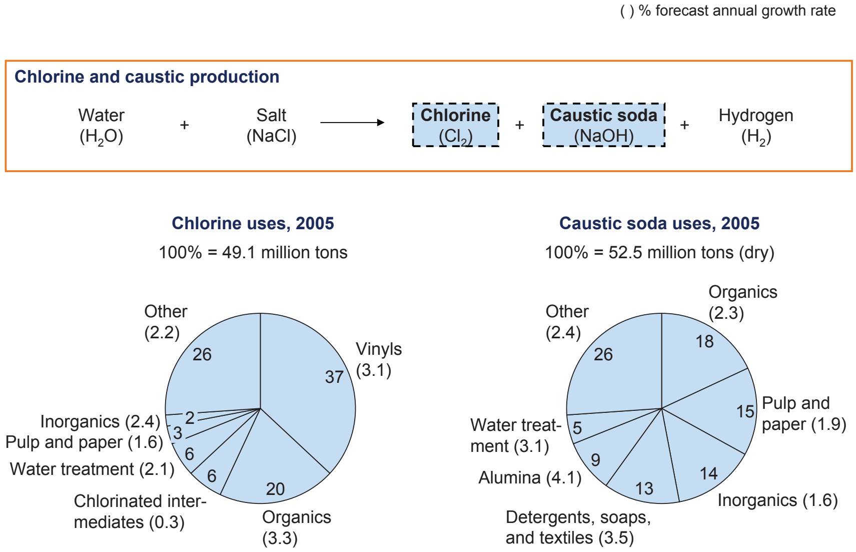
Source: EuroChlor; MGI analysis

### Chlorine-caustic demand

Demand for chlorine and caustic soda comes from a variety of sectors. Chlorine is consumed mainly by the petrochemical industry in the production of vinyl and other organic chemicals, but also in water treatment and in the pulp and paper industry. Caustic soda is used in organic and inorganic chemicals, in pulp and paper, in alumina refining, in water treatment, and in various other applications (Exhibit 34).

## Exhibit 34

### OVERVIEW OF THE CHLORINE-CAUSTIC PRODUCTION AND USES




Source: CMAI; MGI analysis

The evolution of chlorine and caustic demand can be forecast with relative accuracy by analyzing the underlying growth of the sectors that use them. Based on this methodology, we project that chlorine and caustic soda demand will grow at 1.6 percent a year to 2010. We forecast that almost all the new capacity will use membrane-cell technology, and that a portion of the existing mercury-cell technology will be decommissioned and replaced by membrane-cell technology (Exhibit 35).

Chlorine and caustic production tends to be highly localized because of severe regulatory restrictions on the transport of chlorine, and the high cost of transport compared with the price of its products. Demand for chlorine and caustic soda are relatively balanced across regions (Exhibit 36). If a particular region were to become out of balance, caustic soda would be the traded product. The industry would still respond largely to local chlorine market dynamics.

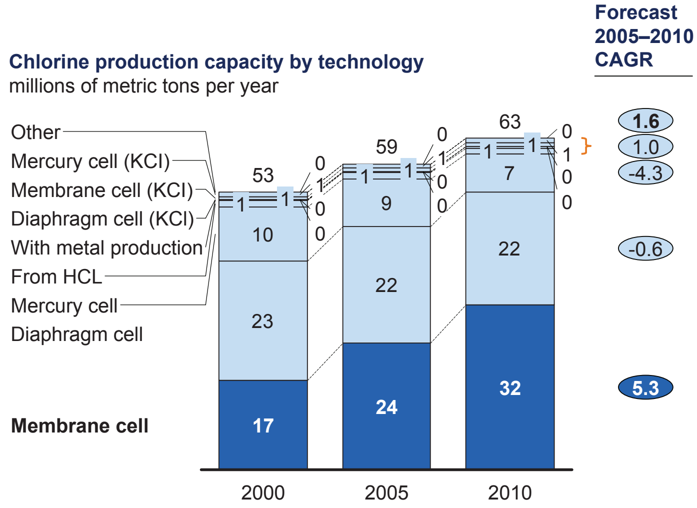
### Energy intensity

The evolution of energy intensity in the chlorine and caustic industry will depend largely on the mix of production processes used. Given that almost all new capacity will use the most energy-efficient membrane-cell technology, most uncertainty relates to the pace of mercury-cell technology decommissioning.

Most of the old technology is situated in developed regions, which have an older industrial base (Exhibit 37). Under current conditions, conversion from mercury-cell technology to membrane-cell technology is not economically viable (Exhibit 38), which

## Exhibit 35

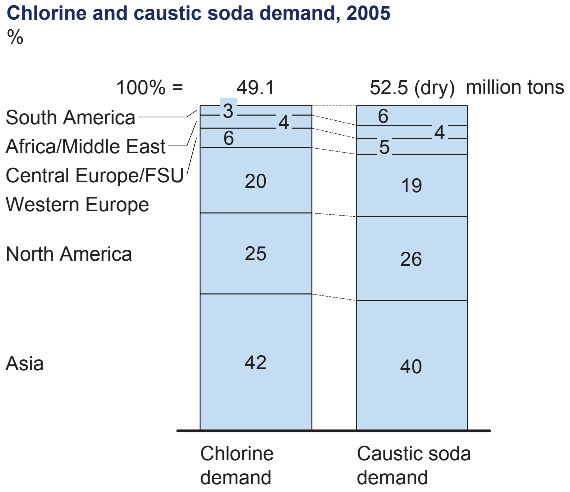
### ALL NEW CHLORINE CAPACITY IS FORECAST TO USE MEMBRANE-CELL TECHNOLOGY




Source: CMAI

## Exhibit 36

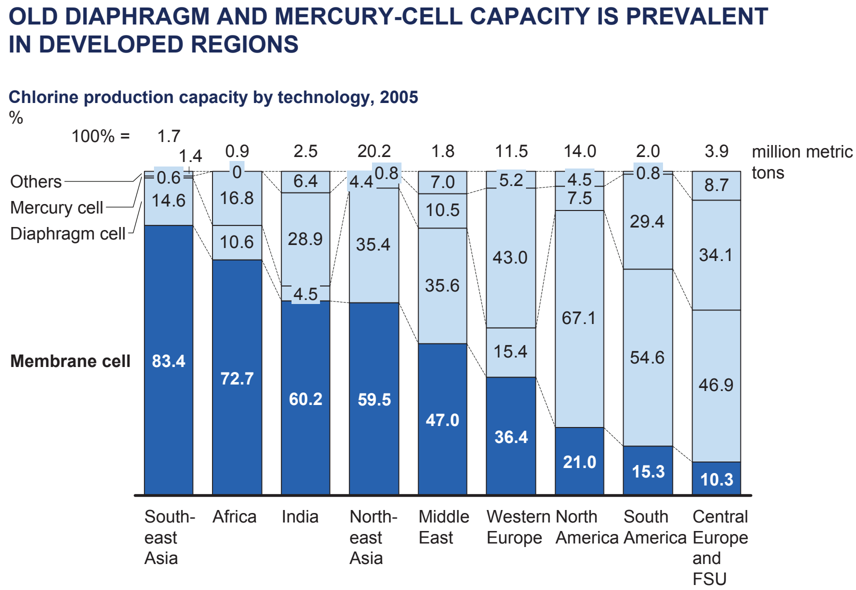
### DEMAND FOR CHLORINE AND CAUSTIC SODA ARE REGIONALLY RELATIVELY BALANCED




Source: CMAI

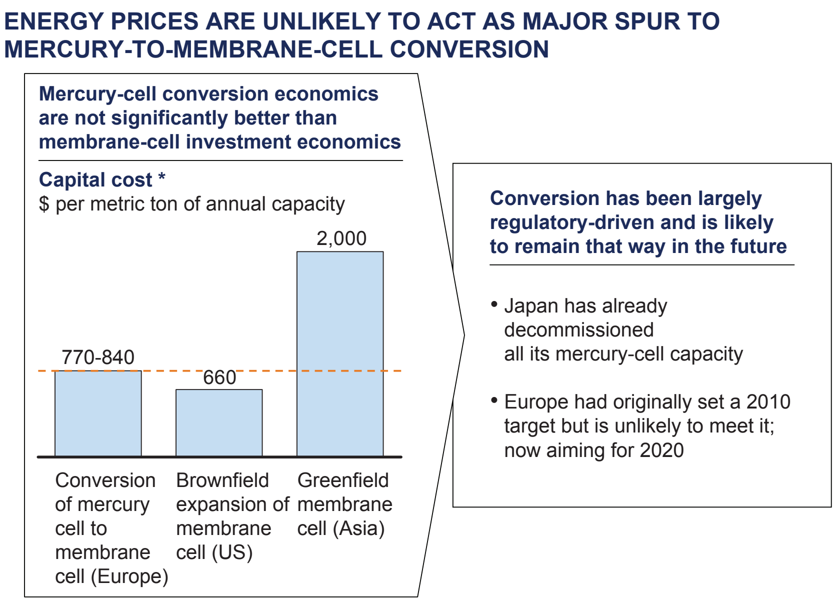
means that the decommissioning of mercury-cell plants will be driven largely by regulation. While Japan has already decommissioned all of its mercury-cell capacity, Europe still uses the technology for a large portion of its installed base. Western Europe initially planned to eliminate mercury-cell plants by 2010; the target is now 2020.

**Exhibit 37**




Note: Numbers may not add to 100% due to rounding.
Source: CMAI; MGI analysis

**Exhibit 38**




* Based on 1997 analyses; assumes a 2.5% inflation rate and a 1.15 $/EUR exchange rate.
Source: European Commission; MGI analysis

## CASE STUDY B—STEEL

No forecast of industrial demand would be complete without an analysis of the ever-increasing demand for steel driven by the booming Chinese and Indian economies.

We project energy demand from the steel industry will grow at a compounded annual rate of 3.1 percent to 2020. This strong growth rate, higher than in past years, is due mainly to the explosive growth in China, where we project the steel-industry energy demand to grow at 7.2 percent per year. Based on our projections, China will produce more than 40 percent of the world's steel by 2020.

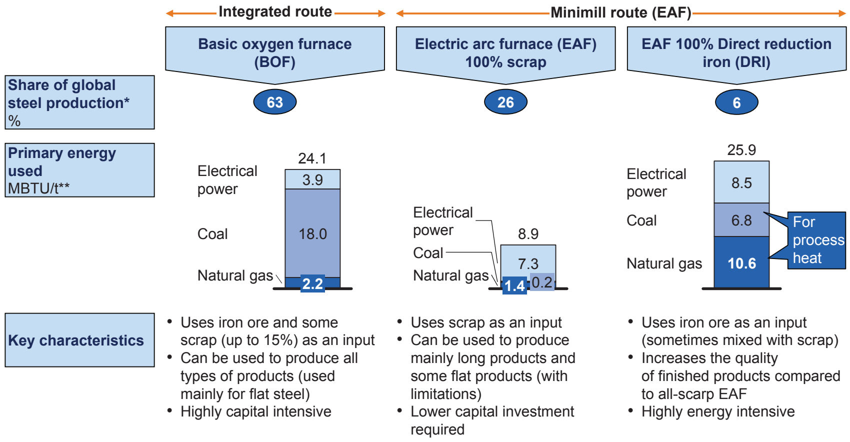
Our forecasts suggest that the supply of scrap steel will not keep pace with the demand for steel, and this will result in a higher proportion of primary (as opposed to secondary) steelmaking. This, in turn, will lead to higher energy use per ton of steel produced, since primary steelmaking is significantly more energy intensive.

### How steel is made

There are two main production processes for steel: the integrated route, also referred to as the basic oxygen furnace process (BOF), and the minimill route, or electric arc furnace process (EAF) (Exhibit 39).

**Exhibit 39**

**OVERVIEW OF THE MAIN STEELMAKING PROCESSES AND THEIR ENERGY INTENSITY**




* Approximately 5% of the worldwide capacity uses the open hearth furnace technology, which is far less efficient and currently in the process of being phased out.

** BTU per metric ton of crude steel including all process steps from cokemaking (BOF), scrap preheating (EAF-scrap), and DRI process (EAF-DRI) to semi-finished steel product (extrusions, plates, hot-rolled coils, and cold-rolled coils) prorated approximately by product mix; figures based on average North American steel mill.

Source: Stubbles (2000); James F. King; MGI analysis

The BOF process uses coal to bring iron ore (iron oxide) to a high temperature. In the presence of oxygen, this triggers a reduction reaction and produces steel, an iron alloy. This is a highly capital- and energy-intensive process. It uses mainly iron ore as an input, but a small share of scrap steel is also typically mixed with the raw materials. The output can be used to produce almost any kind of steel product. In developed regions, the process is used mainly to produce higher-end flat-steel products which cannot be produced by the EAF process.

EAF uses an intense electric current to melt and reduce scrap steel. The process is less energy and capital intensive, but the steel obtained cannot be used in all applications. It is employed mainly for the production of lower-end long-steel products. A variation of the EAF process utilizes lower proportions of iron ore (instead of scrap steel). This direct reduction iron process (DRI) is more energy intensive. However, it requires lower capital investment than BOF, and can work with fuels other than coal, such as natural gas.

An older technology, the open hearth furnace process (OHF), is still sparingly used in some parts of the world. However, this process is significantly more energy intensive than BOF for similar inputs and outputs, and is gradually being phased out because it is uneconomic.

**Steel demand and elasticity**

A country's steel consumption varies enormously, depending on where that country or region stands on the development curve (Exhibit 40). Steel consumption takes off slowly in a country's early development when other materials are cheaper and more readily available. In the middle phase of development, during which a country builds its industrial base and infrastructure, steel consumption shoots up, often at a faster pace than GDP growth. In the mature development stage, steel consumption peaks, and then stabilizes or slowly declines as more sophisticated materials are used (e.g. aluminum, plastics), and as the share of heavy industries declines.

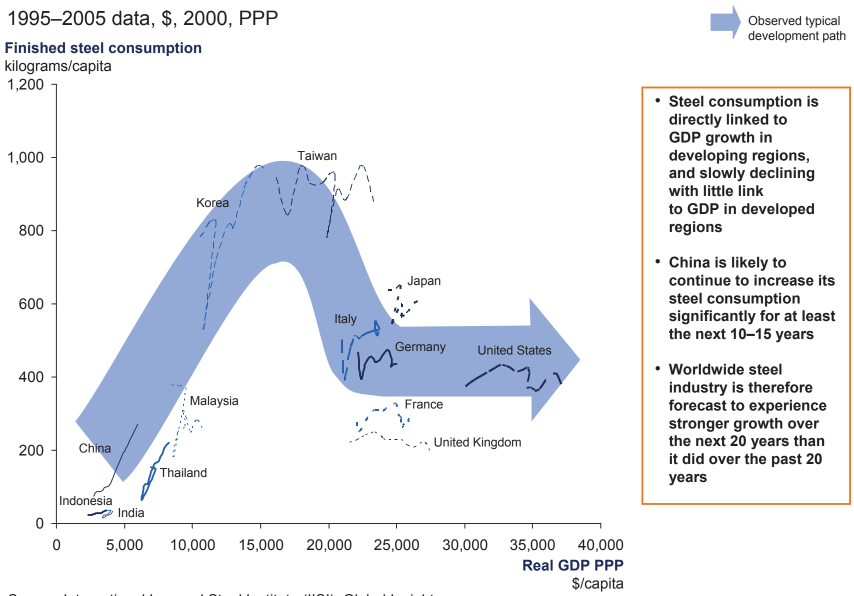
It is tempting to link this staged consumption pattern mainly with trade, with heavy steel-consuming industries locating themselves in developing regions, and consequently appearing to increase consumption at a much faster pace than genuine local end use. However, a closer look at the applications of steel shows that most of the market is still relatively local (Exhibit 41). Therefore, even if trade may affect steel intensity curves slightly, the relationship will still hold at the end-use level.

With many regions of China and India close to an inflection point on the steel-intensity curve, we expect steel demand in these two countries to experience strong compound annual growth to 2020 of 6.7 percent and 7.4 percent respectively (Exhibit 42). Indeed, China will account for more than 40 percent of global steel demand by 2020, and will be the main driver of global demand growth of 2.9 percent a year.

## Exhibit 40

### STEEL CONSUMPTION VARIES ALONG THE DEVELOPMENT CURVE

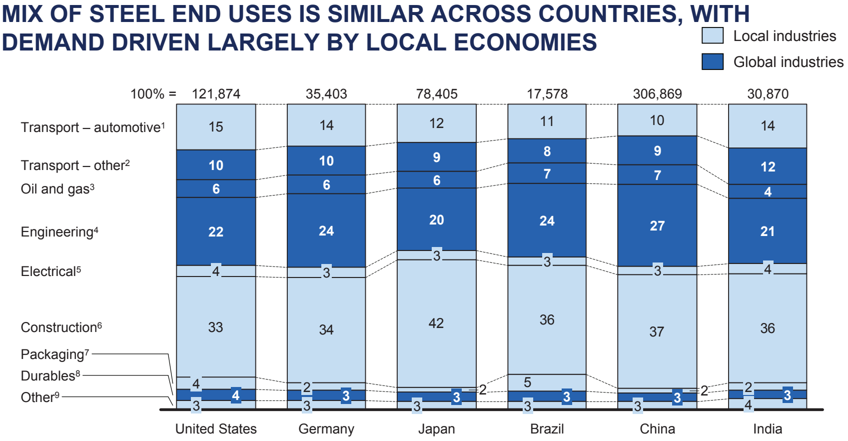
1995–2005 data, $, 2000, PPP




Source: International Iron and Steel Institute (IISI); Global Insight

## Exhibit 41

### MIX OF STEEL END USES IS SIMILAR ACROSS COUNTRIES, WITH DEMAND DRIVEN LARGELY BY LOCAL ECONOMIES

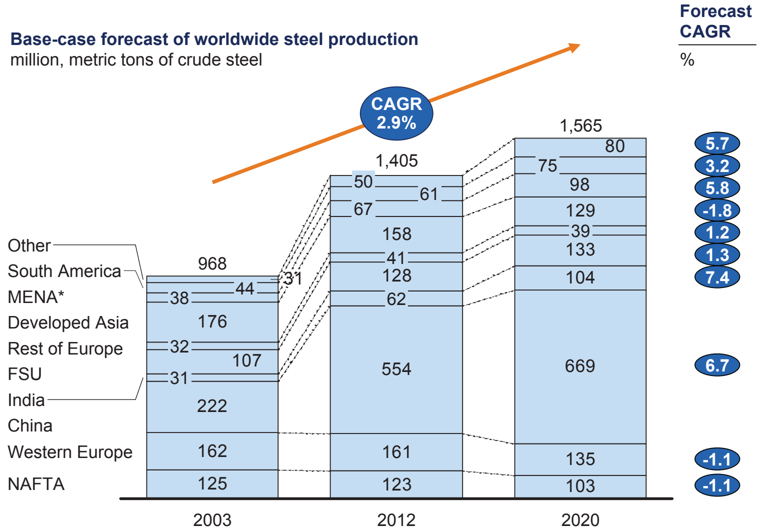



[1] Components for cars, trucks, buses.
[2] Rail transport, shipbuilding and marine equipment, and aircraft and aerospace.
[3] Material for exploration, production, and transmission of oil, gas, water, and other liquids.
[4] Components for machinery for agricultural, mining, and manufacturing; direct consumption in agriculture, mining, tools, and fasteners; components for furniture, storage systems, etc.; and material for intermediate manufacturers not otherwise identified (e.g., forgers).
[5] Components for industrial and commercial electrical equipment; components for industrial, commercial, and domestic electronic equipment (brown goods); and direct consumption for distribution of electricity.
[6] Components for buildings and components for civil engineering, bridges, etc.
[7] Material for cans, closures, drums, etc.
[8] Components for major domestic appliances (white goods) and components for small electric appliances.
[9] Military, other unidentified.

Source: James King; MGI analysis

## Exhibit 42

### GLOBAL STEEL DEMAND IS EXPECTED TO GROW AT 2.9% PER YEAR TO 2020, WITH CHINA DRIVING GROWTH

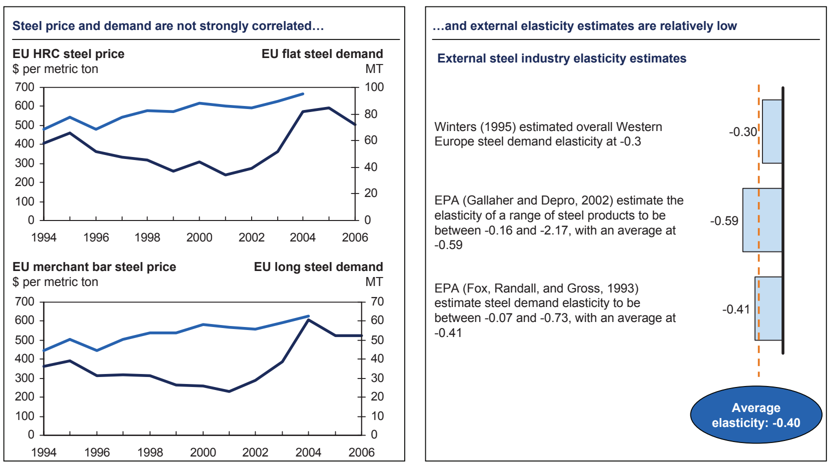



* Middle East and North Africa.
Source: McKinsey Global Steel Model

High energy prices are unlikely to have a direct impact on demand for steel. There is no clear consensus on the price elasticity of steel demand, but experts agree that it is relatively low. The sustained demand growth seen during the recent period of high prices supports this general impression (Exhibit 43).

## Exhibit 43

### STEEL DEMAND IS RELATIVELY INELASTIC TO STEEL PRICE




- **Energy price fluctuations are unlikely to result in significantly less demand from the steel industry**
- **Based on external elasticity calculations, a 50% energy price increase would result in a 10% steel price increase*, which would in turn result in a 4% drop in steel demand; the steel industry energy demand elasticity would therefore be -0.080**

* Fifth quintile BOF producers dedicate on average 20% of their cash costs to energy.
Source: MEPS; IISI; Winters (1995); EPA (Gallaher and Depro, 2002); EPA (Fox, Randall, Gross, JF King); MGI analysis

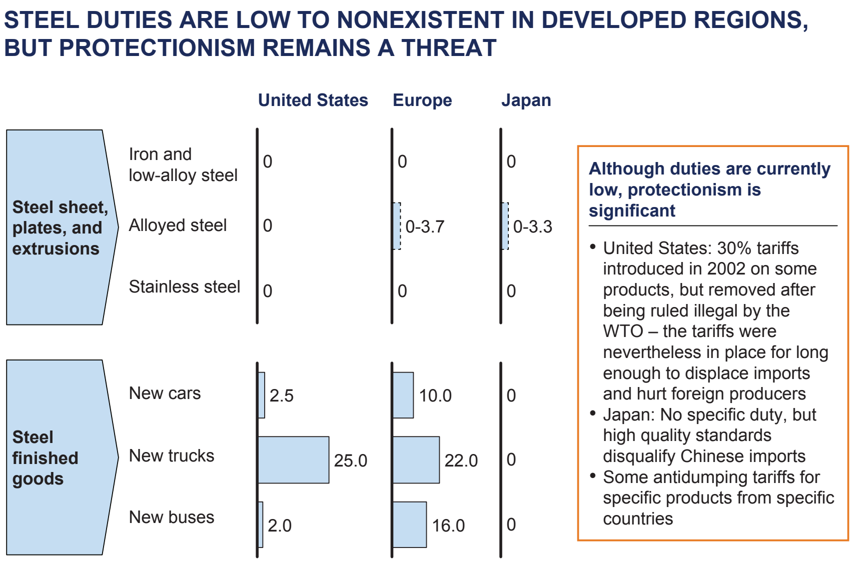
## Regulations and market conditions

Of all the regulations and other external factors that affect the steel industry, three could play a significant role in the industry's energy intensity evolution:

- Changes in import or export tariff structures;
- Asymmetries in greenhouse-gas emission regulation;
- Evolution of the recycling rate in the post-consumer market.

In fact, steel-industry tariffs are unlikely to significantly affect patterns of demand, production, and the resulting energy consumption of the sector. Tariffs on steel and steel product imports are now limited to a few specific products, opening the way to the relocation of some segments of the industry (Exhibit 44). If further relocation were to take place, it would probably be gradual—and some countries may be tempted to respond with the threat of protectionism as in the past, although tariffs in most segments have been ruled illegal by the WTO.

**Exhibit 44**

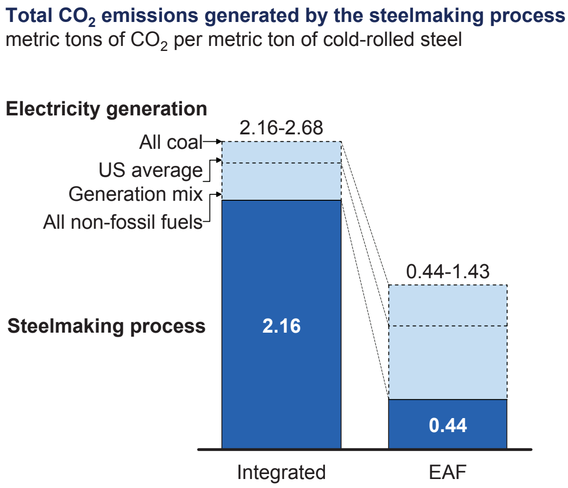



Source: US International Trade Administration; European Commission Taxation and Customs Union; Japan Tariff Association; press search; MGI analysis

The main regulatory uncertainty is the implementation of caps on greenhouse-gas emissions and the asymmetry of implementation across regions. The steel industry emits a substantial amount of $CO_2$. A tax on these emissions could impact producers' economics significantly, and marked carbon tax asymmetry among regions would likely result in some shift in capacity (Exhibit 45).

**Exhibit 45**

### CARBON DIOXIDE EMISSION REGULATIONS COULD HAVE A MAJOR IMPACT ON THE STEEL INDUSTRY




Source: US DOE; Berkeley Lab; MGI analysis

Developments in the recycling rate of steel can also influence its energy demand. Because it takes a much greater amount of energy to convert iron ore into steel than to convert scrap steel into new steel, higher recycling rates mean lower energy intensity for the industry. The accelerated steel-industry growth rate that we forecast will result in a greater need for iron ore, as the supply of scrap steel will significantly lag behind the inflection in demand. In addition, the falling value of a ton of steel relative to rising disposable income will reduce people's incentive to recycle, leading to a decline in recycling rates in most countries (Exhibit 46).

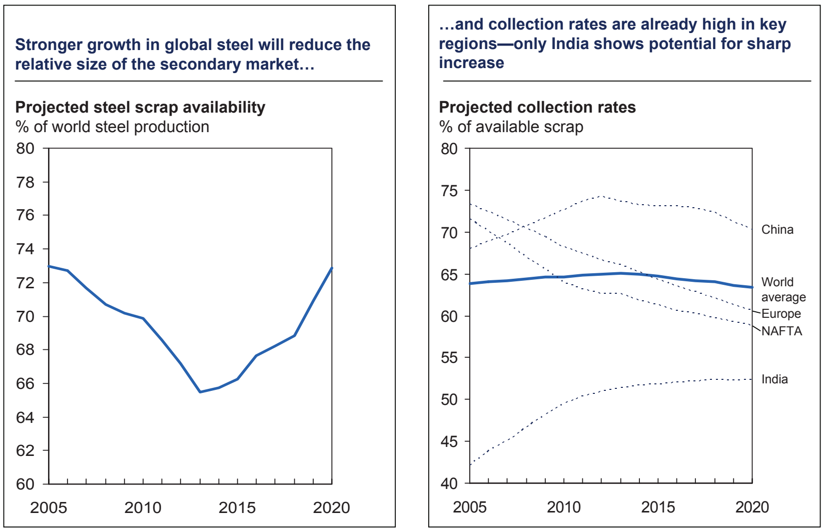
### Reinvestment economics

For many heavy industries, building a plant in a developing region is much cheaper than building one in a developed region. In the steel industry, a new plant is 40 percent cheaper in China and 30 percent cheaper in India and Russia than in North America and Europe (Exhibit 47). Operating costs also vary widely across regions, with developing regions leading the way for integrated steelmaking. The operating-cost advantage of developing regions is not as high for the EAF route, partly because of a scarcity of scrap in these regions (Exhibit 48).

Combining data on capital and operating costs for BOF, we conclude that developing regions are sufficiently competitive to address any new demand in developed regions, particularly for flat-steel production (Exhibit 49). Under the current cost structure, we estimate the full cost of building and operating a new integrated

## Exhibit 46

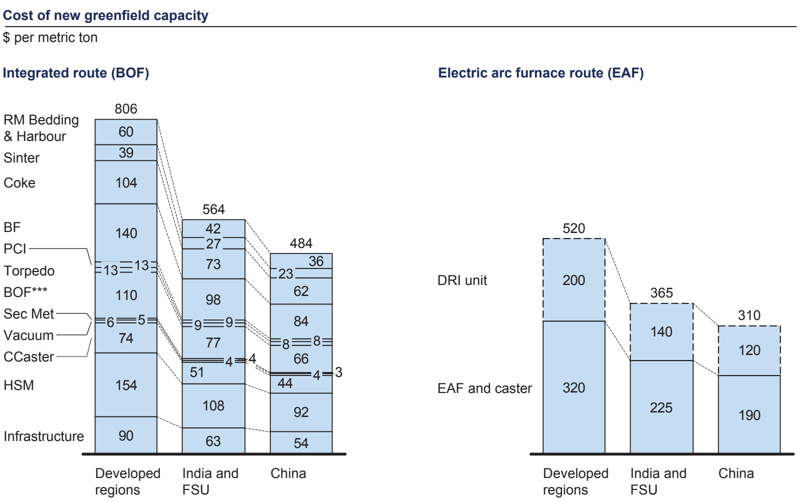
### ACCELERATED STEEL-INDUSTRY GROWTH WILL BOOST DEMAND FOR IRON ORE IN THE FACE OF A SCRAP SHORTAGE




Source: IISI; MGI analysis

## Exhibit 47

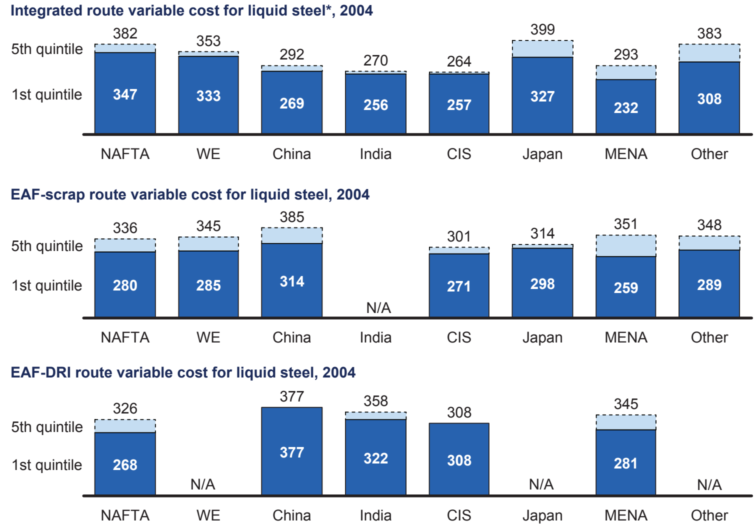
### REINVESTMENT ECONOMICS VARY SIGNIFICANTLY BY REGION




* Based on a 5Mt plant.
** Based on a 1Mt plant.
*** Includes lime and oxygen plants.
Source: MGI analysis

## Exhibit 48

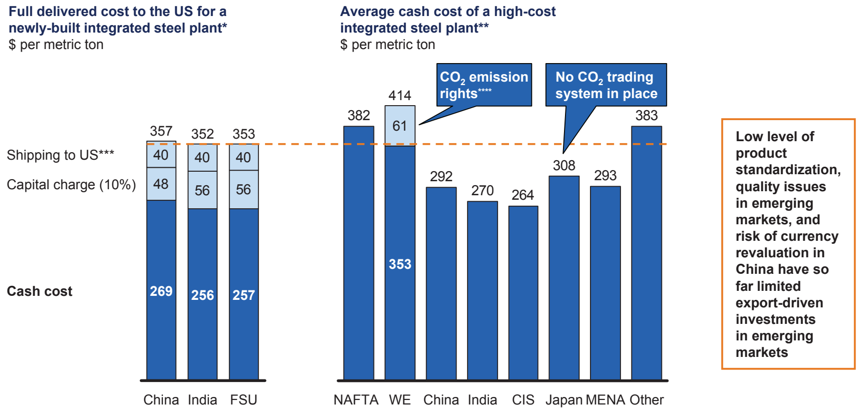
### OPERATING COSTS VARY WIDELY AMONG AND WITHIN REGIONS




Note: Costs are inflated by higher-than-average scrap and iron ore costs in 2004.
* Pig-iron input at market price was used for all mills to estimate full opportunity cost.
Source: J.F. King; MGI analysis

## Exhibit 49

### THE FLAT STEEL INDUSTRY IS PRONE TO SIGNIFICANT RELOCATION FOR PRODUCT SEGMENTS THAT CAN BE EXPORTED EASILY

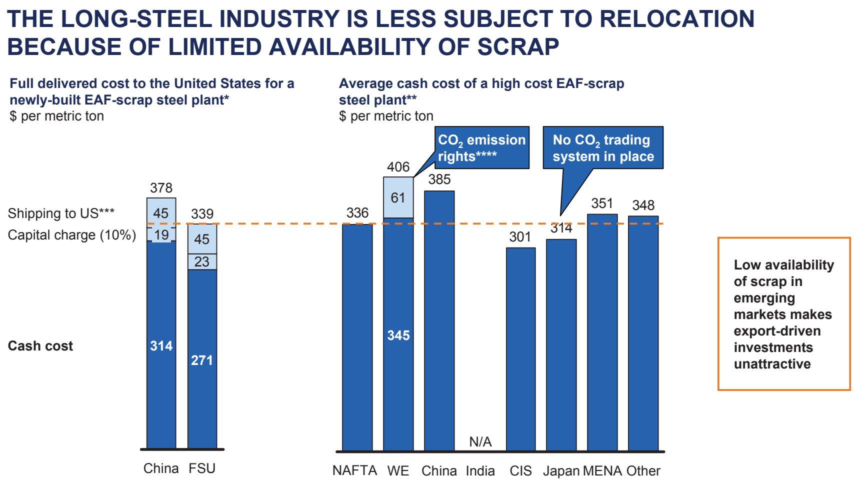



* Assumes newly-built mill is positioned in the middle of the first quintile of the local cost curve; hot steel used as a generic product (no rolling cost included).
** Average for integrated steel plants in the fifth quintile of the local cost curve; hot steel used as a generic product (no rolling cost included).
*** Estimate, based on past 25-year average shipping rate, assuming ship returns empty; includes loading, offloading, charter cost, fuel costs, inventory costs while at sea, and insurance.
**** Assuming $25 per metric ton of $CO_2$ (average for May 2005 to May 2006); the market for GHG emission in Europe is still very volatile (the price fell by more than 50% at the end of April 2006), and there is significant uncertainty about the system's future. There is therefore significant uncertainty around how long-term business decisions will be made with regards to $CO_2$ emission cost.
Source: J.F. King; MGI analysis

steel mill in Eastern Europe, India, or China and shipping the production to the Western markets at between $360 and $370 per metric ton. This is significantly lower than the continued operating costs of high-cost (marginal) mills in North America ($382 per metric ton) or Western Europe ($353 per metric ton, or $414 per ton when opportunity cost of $CO_2$ emissions is taken into account).

The long-steel industry, served most efficiently by EAF, is less subject to relocation because there is no clear operating-cost advantage in developing regions, and any edge these regions enjoy on capital costs is barely enough to compensate for additional shipping costs (Exhibit 50).

**Exhibit 50**




* Assumes newly-built mill is positioned in the middle of the first quintile of the local cost curve; hot steel used as a generic product (no rolling cost included).

** Average for EAF-scrap steel plants in the fifth quintile of the local cost curve; hot steel used as a generic product (no rolling cost included).

*** Estimate, based on past 25-year average shipping rate, assuming ship returns empty; includes loading, offloading, charter cost, fuel costs, inventory costs while at sea, and insurance.

**** Assuming $25 per metric ton of $CO_2$ (average for May 2005 to May 2006); the market for GHG emission in Europe is still very volatile (the price fell by more than 50% at the end of April 2006) and there is significant uncertainty about the system's future. There is therefore significant uncertainty around how long-term business decisions will be made with regards to $CO_2$ emission cost.

Source: J.F. King; MGI analysis

The development of DRI capacity using stranded gas from the Middle East is another factor that could potentially reshape the global production pattern. However, our analysis finds that these projects could compete for new capacity only (Exhibit 51). Such projects would not displace existing plants, which compete on a variable-cost basis. Given the low level of demand growth forecast in developed regions, this factor is likely to be marginal.

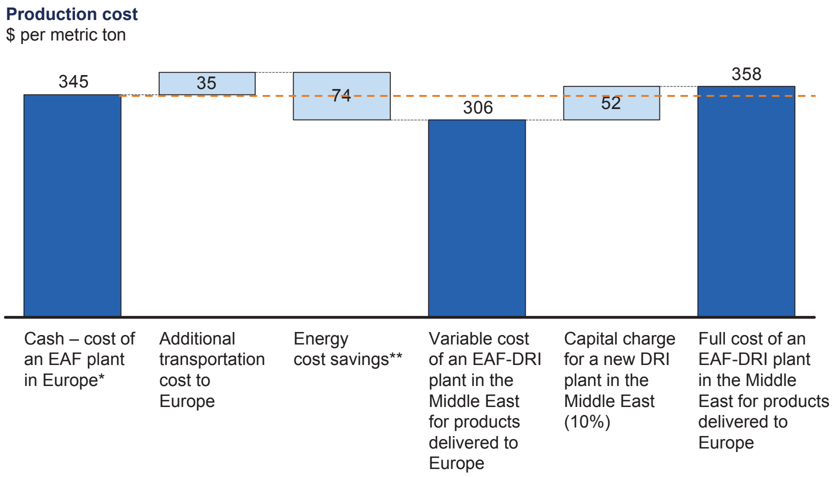
Overall, we anticipate that there will be more significant relocation in flat steel—mostly integrated—than in the long-steel segment—mostly minimill (Exhibit 52).

In terms of regions, we project very strong growth in China’s steelmaking capacity, with most of the remaining growth in global production capacity in those parts

## Exhibit 51

### EAF-DRI IN THE MIDDLE EAST IS INCREMENTALLY ATTRACTIVE BUT IS UNLIKELY TO DISPLACE EXISTING EAF CAPACITY

ESTIMATES




* At 2005 prices for raw materials, excludes $CO_2$ costs.

** Assumes a $2.87/MMBTU natural-gas price differential between the Middle East and the United States/Europe.

Source: MGI analysis

## Exhibit 52

### THE FLAT-STEEL MARKET IS MORE LIKELY TO BECOME INCREASINGLY GLOBAL

● Favors global production/sales
○ Inhibits global production/sales

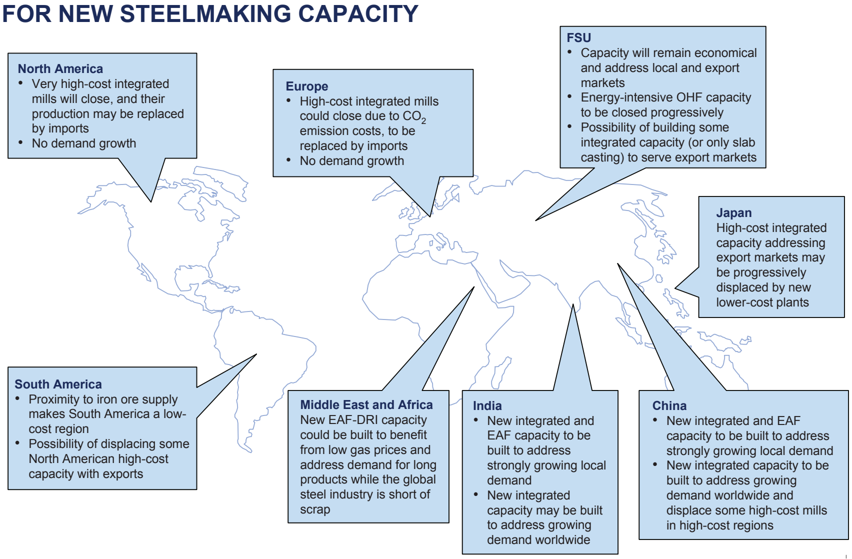
| | Industry characteristics | Legal/regulatory characteristics | Organizational characteristics | Overall rating |
|---|---|---|---|---|
| **Flat steel** | • Significant full and variable cost differences across regions<br>• Global raw materials sourcing and weight reduction in the production process<br>• Multiple end products create a barrier, can be overcome with slab trade | • Regulatory asymmetries among regions (e.g., $CO_2$)<br>• Relatively low trade barriers | • Unions play strong role | • More opportunities becoming available to address stronger forecast growth |
| **Long steel** | • High transportation cost compared to product value<br>• Product's shape makes it less convenient to ship<br>• Limited scrap availability in low-cost regions | • Regulatory asymmetries among regions (e.g. $CO_2$)<br>• Relatively low trade barriers | • Unions play strong role | • High transportation cost and local sourcing of materials |

Source: Interviews; MGI analysis

of South America that lie close to iron ore reserves, and in FSU/Eastern Europe in geographies that are close to markets in Western Europe and where costs are low. As for Japan, Western Europe, and North America, stagnant local demand and high production costs will limit capacity investments and may even cause small declines in production (Exhibit 53).

**Exhibit 53**

**CHINA, SOUTH AMERICA, AND FSU/EASTERN EUROPE WILL ACCOUNT FOR NEW STEELMAKING CAPACITY**




Source: MGI analysis

The long investment cycles in the steel industry provide an excellent snapshot of the short- and medium-term future, as almost all major capacity investments for the next four to six years have already been announced (Exhibit 54). It would therefore take several years of change to the global market materially to impact our base-case projection for the industry.

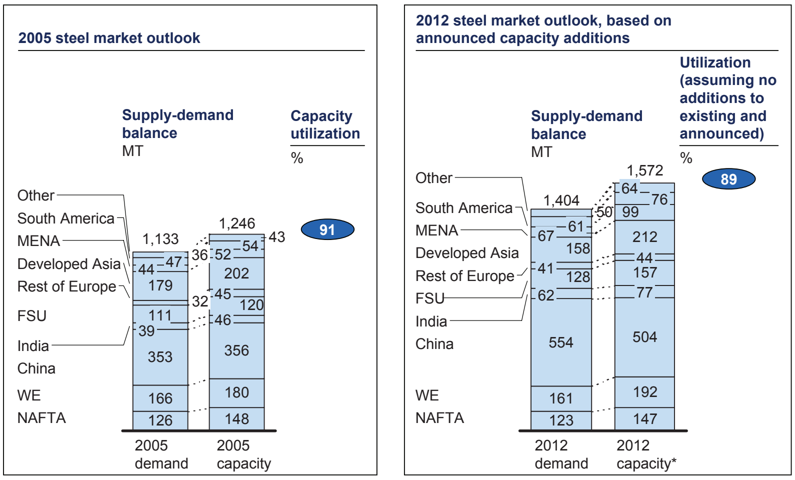
### Energy intensity

Energy intensity varies significantly among steel plants, largely reflecting the different production process used and the scale of the plant (Exhibit 55). Even within a single type of production process, we observe substantial variations in energy efficiency, with developing regions lagging behind developed regions. This is largely explained by scale. China, for instance, has many small steel mills, known to consume far more energy per ton produced than large, state-of-the-art integrated plants.

Indeed, a key uncertainty over future steel industry energy consumption relates to the substantial new capacity being built in China and, specifically, how energy

## Exhibit 54

### STEEL INDUSTRY'S MEDIUM-TERM OUTLOOK IS RELATIVELY CLEAR BECAUSE OF LONG INVESTMENT CYCLES




Note: 2005 demand based on a forecast made in early 2005, according to the International Iron and Steel Institute; actual figures have been 7% higher, with capacity utilization around 91% worldwide.

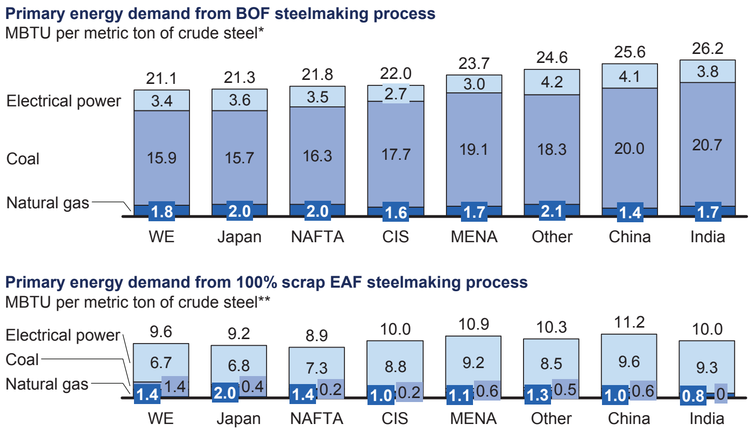
* Announced capacity additions and forecast capacity creep added to current steelmaking capacity, net of announced decommissioning.

Source: McKinsey Global Steel Model; International Iron and Steel Institute; press search; annual reports; broker reports; supplier websites; MGI analysis

## Exhibit 55

### INTEGRATED STEELMAKING EFFICIENCY VARIES SIGNIFICANTLY ACROSS REGIONS, LESS FOR EAF

ENERGY INTENSITY FIGURES FOR EMERGING REGIONS ARE ESTIMATES




| BOF | WE | Japan | NAFTA | CIS | MENA | Other | China | India |
|---|---|---|---|---|---|---|---|---|
| Total | 21.1 | 21.3 | 21.8 | 22.0 | 23.7 | 24.6 | 25.6 | 26.2 |
| Electrical power | 3.4 | 3.6 | 3.5 | 2.7 | 3.0 | 4.2 | 4.1 | 3.8 |
| Coal | 15.9 | 15.7 | 16.3 | 17.7 | 19.1 | 18.3 | 20.0 | 20.7 |
| Natural gas | 1.8 | 2.0 | 2.0 | 1.6 | 1.7 | 2.1 | 1.4 | 1.7 |

| EAF | WE | Japan | NAFTA | CIS | MENA | Other | China | India |
|---|---|---|---|---|---|---|---|---|
| Total | 9.6 | 9.2 | 8.9 | 10.0 | 10.9 | 10.3 | 11.2 | 10.0 |
| Electrical power | 6.7 | 6.8 | 7.3 | 8.8 | 9.2 | 8.5 | 9.6 | 9.3 |
| Coal | 1.4 | 0.4 | 0.2 | 0.2 | 0.6 | 0.5 | 0.6 | 0 |
| Natural gas | 1.4 | 2.0 | 1.4 | 1.0 | 1.1 | 1.3 | 1.0 | 0.8 |

* For one metric ton of crude steel used in the production of a reference cold-rolled steel sheet, including the following operations: coke oven, sinter, blast furnace, basic oxygen furnace, refining, continuous thick slab casting, hot rolling, and cold rolling.

** For one metric ton of crude steel used in the production of a reference steel extrusion, including the following operations: scrap preheating, EAF process, continuous casting.

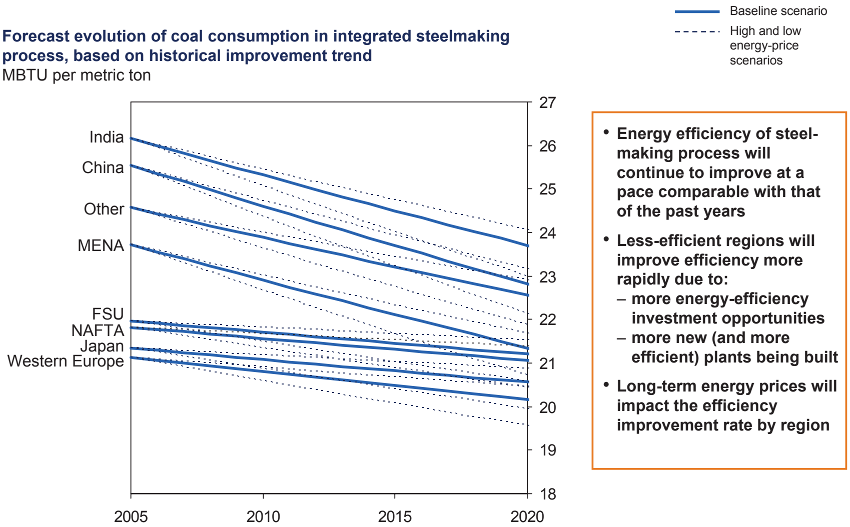
Source: J.F. King; MGI analysis

intensive it will be. There are differing views on this point. Because the scale of almost all new capacity now being built in China is at least comparable to world standards, some believe that the impending explosive growth in China's steel industry will meet global energy-efficiency standards. This view is supported by the fact that China has government programs in place aimed at closing all very small and inefficient steel mills. However, while we believe that the capital stock expansion will improve average efficiency, any change will be slow and gradual. China's installed base is both huge and inefficient. Moreover, the country's voracious appetite for steel makes the decommissioning of inefficient mills unlikely.

Our energy efficiency forecasts are based on historical rates of evolution (Exhibit 56). Energy intensity typically improves by 0.1 to 0.6 percent per year in existing plants in developed regions. Meanwhile, rates of improvement tend to be higher in developing regions that have greater scope to replace inefficient installed capacity with higher-efficiency new plants.

**Exhibit 56**

**STEELMAKING ENERGY EFFICIENCY WILL IMPROVE AT HISTORICAL RATES, WITH MORE PROGRESS IN DEVELOPING REGIONS**



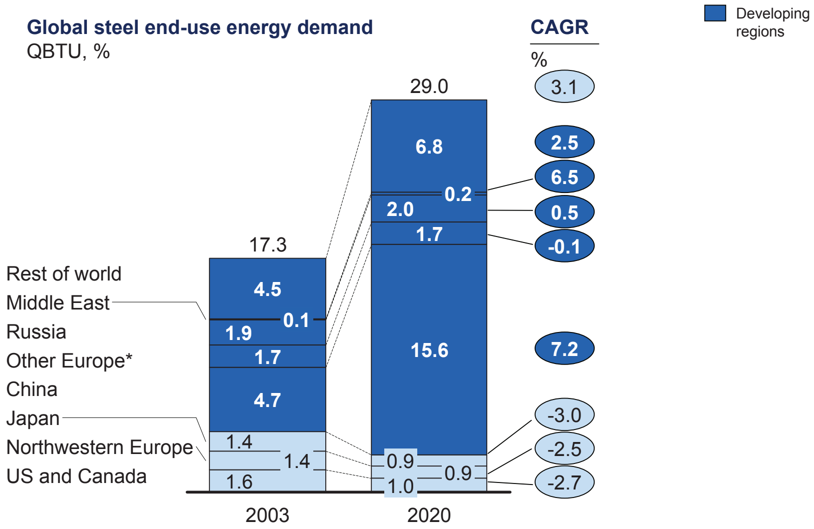

Source: MGI analysis

## Energy demand projections

Based on our aggregated forecasts and our base-case energy price and GDP-growth scenarios, energy consumption in the steel industry will increase at a slightly higher rate than steel demand to 2020—3.1 versus 2.9 percent a year—due in large part to higher growth in lower energy efficiency regions, and to the scarcity of scrap, which increases the proportion of more energy-intensive BOF and EAF-DRI steelmaking (Exhibit 57). This impacts China, where the stronger growth in energy-intensive integrated steelmaking dwarfs projected energy-efficiency.

**Exhibit 57**

**ENERGY-DEMAND GROWTH OF STEEL INDUSTRY WILL BE SLIGHTLY HIGHER THAN UNDERLYING STEEL-DEMAND GROWTH TO 2020**



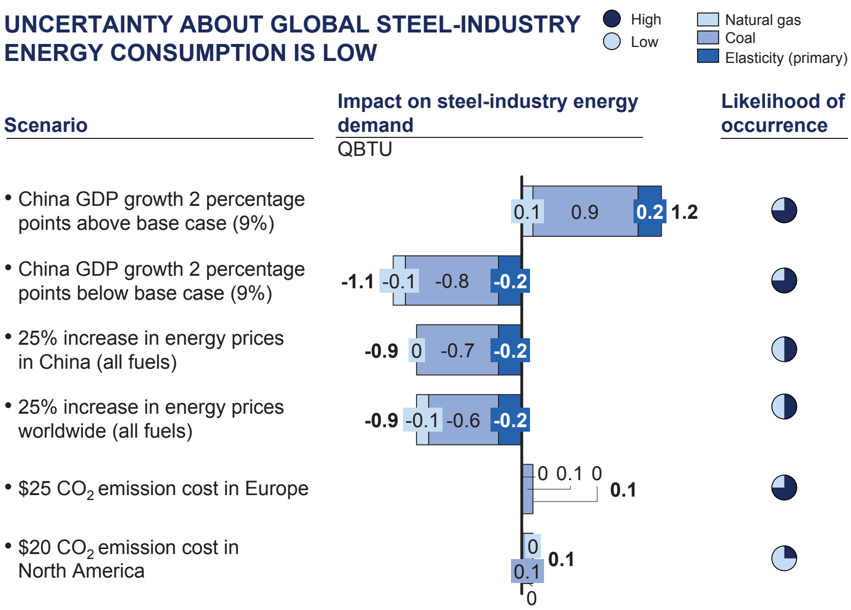

* Including Mediterranean Europe and North Africa, and Baltic/Eastern Europe.
Source: IEA; MGI Global Energy Demand Model

As we have noted, there is little uncertainty about steel-industry energy demand in the medium term—i.e. the next six years—because of long investment cycles. However, some factors are not entirely predictable, notably energy prices in China which could have a small impact on energy demand from the steel industry. For example, a coal price increase of 25 percent could reduce local coal demand by 3 percent. Chinese GDP growth and, to a lesser extent, $CO_2$ emission prices also create some uncertainty (Exhibit 58).

However, the risk of a major shock affecting energy demand in the steel industry is very low (Exhibit 59). The steel industry is well established and is therefore very unlikely to see radical changes in technology in the near future; all improvements will be incremental. Material substitution is already established in various end-user segments, and steel has proven to be by far the preferred material for various applications given its physical properties and low cost. Raw materials, mainly iron ore and coal, are far from being depleted. An unexpected economic downturn and evolving greenhouse-gas emission regulation would have a clear impact but, overall, the chance of a major divergence from our base case in the short to medium term is relatively low.

## Exhibit 58

### UNCERTAINTY ABOUT GLOBAL STEEL-INDUSTRY ENERGY CONSUMPTION IS LOW




Source: McKinsey Global Steel Model; interviews; MGI analysis

## Exhibit 59

### RISK OF A SIGNIFICANT SHOCK TO STEEL DEMAND IS LOW

High / Low

| Type of shock | Potential scenario | Current context | Risk of a shock |
|---|---|---|---|
| Technological advances in production process | • An increasing range of flat products can be produced with the EAF process<br>• A new, less expensive process becomes available | • Steady, but slow technological improvement over the past 15 years<br>• No radically different process under development |  |
| Demand migration to/from other material | • Materials other than steel become more attractive in construction, metal goods, or automotive<br>• New product or process requires a significant amount of steel | • No cheaper material with similar properties<br>• Steel demand very high – the new use would have to use a lot of steel to make a difference |  |
| Limited supply of raw materials | • Scarcity of coal<br>• Scarcity of iron core | • 180 years of coal reserves*<br>• 70 years of proven reserves, 270 years of estimated total reserves* |  |
| Sudden change in economic growth | • Global economic crisis<br>• Strong growth in one region | • Unpredictable, but never really happened<br>• China and India, the most popular nations, are well covered by forecasters |  |
| New environmental regulation | • GHG regulation made tougher<br>• Regulation limiting coal use | • China and the United States are going in the opposite direction in both cases |  |

* At current consumption rate.
Source: MGI analysis

## CASE STUDY C—PULP AND PAPER

Energy demand from the pulp and paper industry is forecast to grow at a compounded annual rate of 1.9 percent to 2020. This growth is driven by final-demand growth for paper products, mainly in developing regions, and in some specific segments for developed regions (e.g. containerboard). Energy demand will, however, grow at a slower pace than the underlying industry growth due to a slow change in product mix and to decreasing energy intensity.

The pulp and paper industry's global energy consumption accounts for 4.1 percent of total industrial end-use energy demand. This industry is quite different from the chemical and steel industries in its use of energy. It doesn't use energy as a feedstock and doesn't require the very high temperature levels in the transformation process that steel and some chemicals do. In this respect, therefore, it is very similar to industries such as food processing and many light-manufacturing sectors.

Pulp and paper production benefits from a substantial degree of self-generated energy including, for example, that extracted onsite from biomass made of bark, water-treatment sludge, and rejected wood. The leftovers from the early stages of the production process, mainly pulping, are also a potential source of energy. However, biomass does not provide enough energy for the whole transformation process, and additional energy has to be purchased. Power generation and heating are the two main processes requiring energy. Electricity is used mainly for board and paper making, but also for lighting and air-conditioning. Heat production is required, particularly in the drying stage. Usually mills produce the heat they will need onsite.

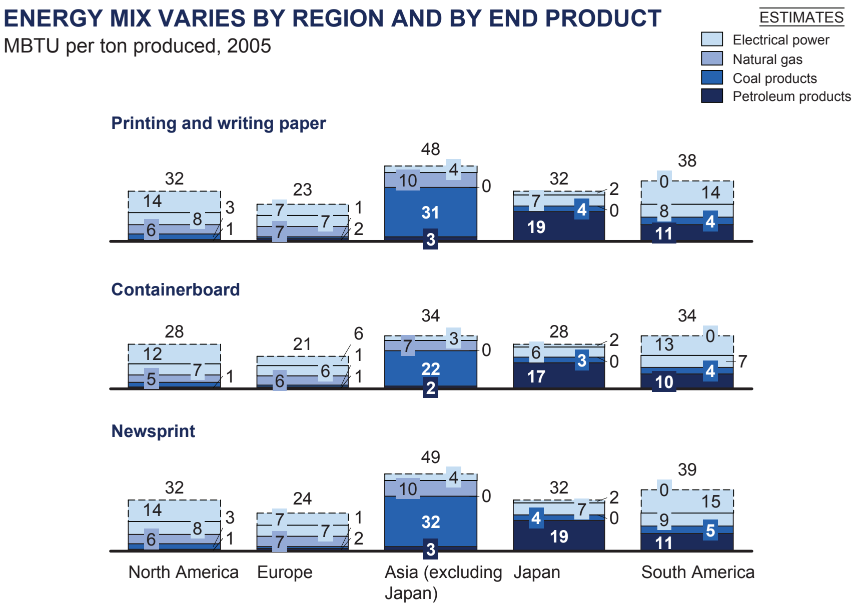
Energy mix varies by region and by end product (Exhibit 60). Resource availability at the regional level is a major factor; China's pulp and paper production is highly reliant on coal, whereas Finland's uses hardly any.

**How paper is made**

All pulp and paper end products use cellulose fiber—a natural component of plant tissue, which is extracted from trees or recovered paper—as a basic ingredient. The fiber is used to produce one of three main types of pulp, all of which have very different energy intensity profiles:

1. In the mechanical-pulping process, trees are first debarked and chipped, then ground into pulp. The pulp is then diluted in water and fashioned into a large continuous sheet, which is dried and sometimes subjected to an additional finishing treatment. Mechanical pulp can utilize both hardwood

**Exhibit 60**




Source: LBNL; Environment Canada; World Bank; IEA; MGI analysis

and softwood as an input. It is used primarily for newsprint and certain coated and uncoated printing and publication papers.

2. In the chemical-pulping process, wood chips are mixed with a solvent that dissolves lignin (the natural "glue" sticking fibers together), thus freeing the fibers. The mixture then undergoes bleaching and drying processes. Once the chemical pulp is obtained, the papermaking process is similar to that of mechanical pulping. Chemical pulp uses mostly hardwood as an input, but softwood can also be used. End products are typically writing papers, printing and publication papers (coated or uncoated), and many packaging applications.

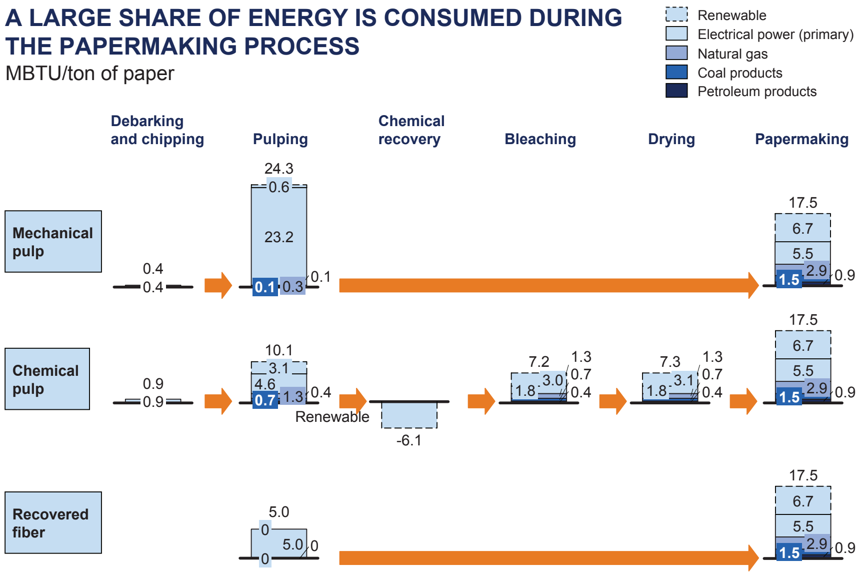
3. Recovered fibers are collected from pre- and post-consumer waste-paper products. The paper is rendered back into pulp and typically mixed with primary pulp to produce newsprint, packaging products, and tissue papers.

Papers using mechanical pulp are the most energy intensive because of the extensive mechanical grinding involved in pulp manufacture (Exhibit 61). On average, papers produced with mechanical pulp in the United States use 42.2 million BTUs (MBTU) of primary energy per metric ton. Chemical pulping is less energy intensive for two reasons. First, there is no fine grinding involved; second, the dissolved lignin can be recovered in the pulping process and used as an energy source. Papers produced in this way in the United States use on average 36.9 MBTUs of primary energy per metric ton. Paper made from recovered fiber uses 22.5 MBTUs per metric ton (Exhibit 62).

## Exhibit 61

### A LARGE SHARE OF ENERGY IS CONSUMED DURING THE PAPERMAKING PROCESS

MBTU/ton of paper

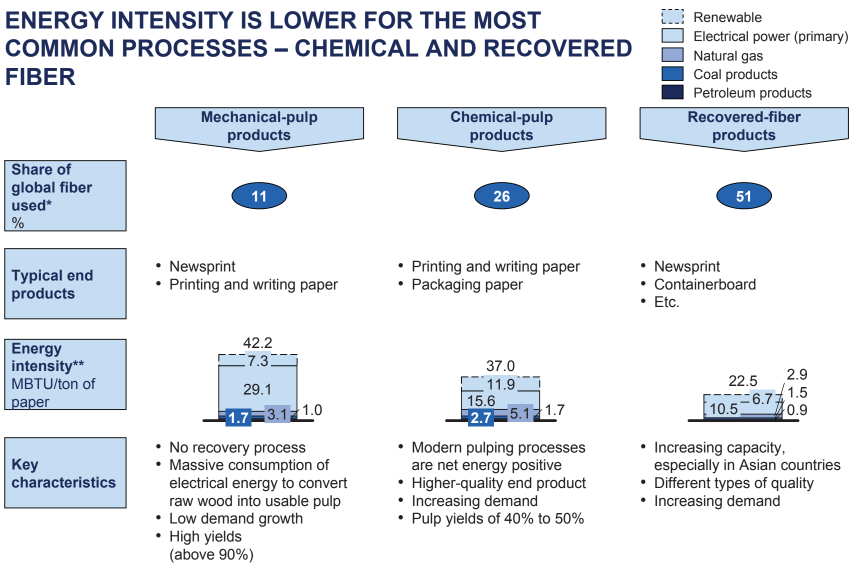



* Case study based on North American technology in 2005.

Source: LBNL; Environment Canada; MGI analysis

## Exhibit 62

### ENERGY INTENSITY IS LOWER FOR THE MOST COMMON PROCESSES – CHEMICAL AND RECOVERED FIBER




* US shares; does not add up to 100% due to other processes not covered.

** Case study based on North American technology in 2005.

Source: LBNL; Resource Information Systems Inc. (RISI); Paperloop; MGI analysis

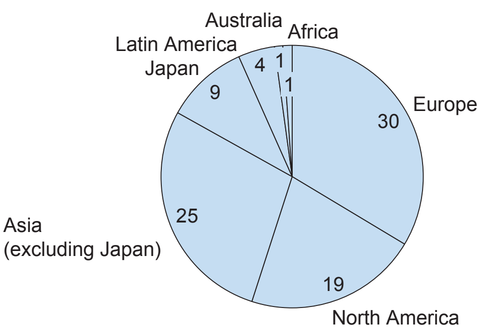
## Pulp and paper demand and elasticity

The pulp and paper market has historically been relatively regional, with sub-continental variations (Exhibit 63). Softwood-rich, colder regions within each subcontinent produce both mechanical and chemical pulp, while hardwood-rich, temperate regions tend to produce mostly chemical pulp. Although there is some global trade in the white-paper segment, volumes are relatively low. For each region, production levels are close to local demand levels (Exhibit 64), although some significant imbalances exist at the grade level.

**Exhibit 63**

**PULP AND PAPER PRODUCTION IS BROADLY SIMILAR IN SIZE IN EUROPE, NORTH AMERICA, AND ASIA**
%

**Worldwide pulp and paper production by region, 2005**
100% = 265 million metric tons



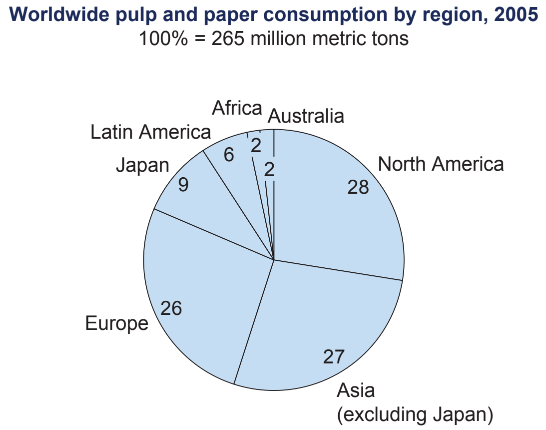

Source: RISI

However, more trade takes place at the intermediate pulp level, which can be considered a global market. Due to the development of a solid post-consumption recycling infrastructure, fibers from recovered paper are a growing source of raw material. Developed regions are major providers of recovered paper, with the United States, United Kingdom, Germany, and Belgium the biggest exporters. Meanwhile, Asia remains a large importer. Plants producing secondary fiber are more geographically dispersed, and this triggers more intense trade flows. Despite the importance of trade in pulp, the economics are such that pulp mills are always located close to the fiber source, whether it be a forest or a consumer market for recovered paper. For this reason, the market structure is insensitive to regional or global energy-price fluctuations.

**Exhibit 64**

## OVERALL PULP AND PAPER PRODUCTION LARGELY REFLECTS LOCAL DEMAND

%



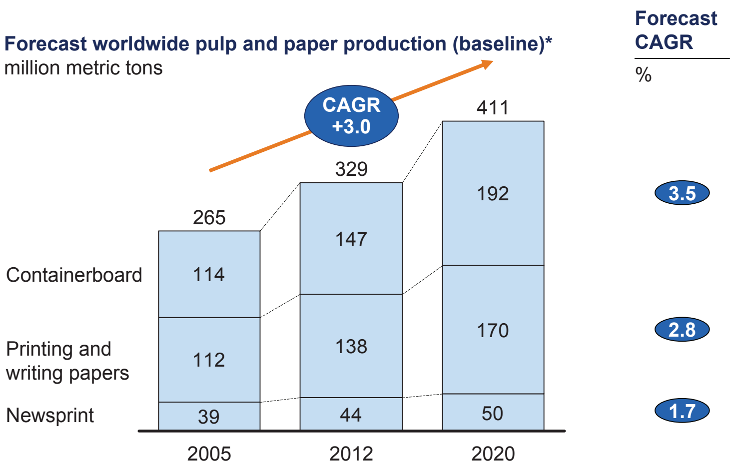

Source: RISI

In 2005, containerboard accounted for 43 percent of the global pulp and paper industry, printing and writing paper for 42 percent, and newsprint for the remaining 15 percent. Industry experts forecast that the industry will grow at an overall rate of 3 percent per annum over the next 15 years. Containerboard is expected to see the strongest growth at 3.5 percent per year, driven by the ever-increasing complexity in supply chains. White papers are expected to grow at 2.8 percent per year, while newsprint should grow at only 1.7 percent per year. It is notable that containerboard and white papers are less energy intensive than newsprint (Exhibit 65).

In 2005, Asian countries together consumed some 37 percent of worldwide paper products, with Japan accounting for 9 percent. Developing regions, particularly in Asia, will increase pulp and paper production overall to meet high demand. In the longer term, per capita consumption is expected gradually to align with that of developed regions, in line with economic development. Developing economies are still far from being mature markets. In Asia (excluding Japan), for instance, per capita consumption of paper products is more than eight times lower than in North America or Western Europe. Overall, North America represented 28 percent of global demand in 2005, and Europe 26 percent. Growth rates in developed regions vary between zero and 2.6 percent as the continuous decline in demand for newsprint in North America exerts downward pressure on industry growth (Exhibit 66).

## Exhibit 65

### THE CONTAINERBOARD AND PRINTING AND WRITING PAPERS SEGMENTS WILL DRIVE DEMAND GROWTH

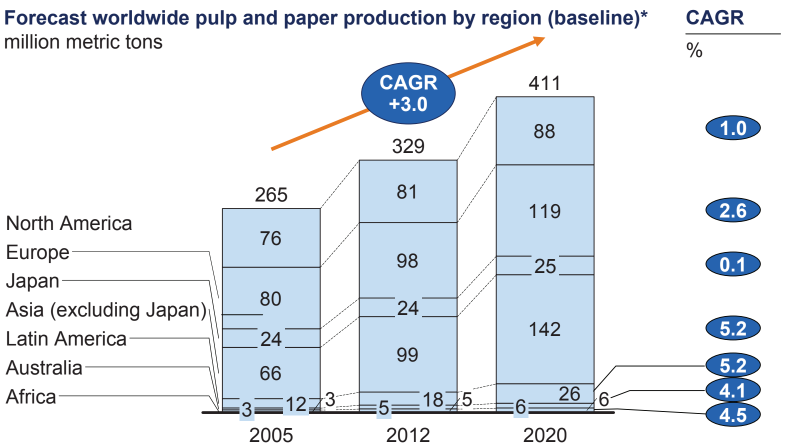



* Estimates summing the total printings, newsprint, and containerboard markets, which represent about 80% of the pulp and paper market.

Source: RISI

## Exhibit 66

### DEVELOPING REGIONS WILL INCREASE PULP AND PAPER PRODUCTION TO MEET FAST-GROWING LOCAL DEMAND



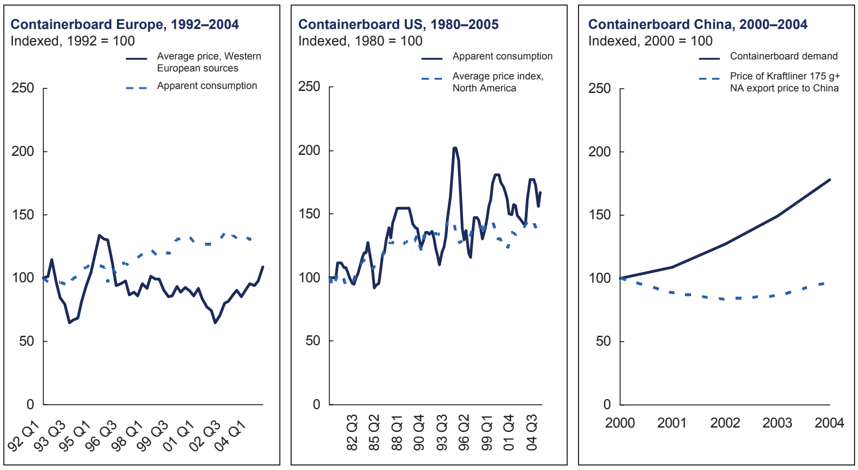

* Estimates summing the total printings, newsprint, and containerboard markets, which represent about 80% of the pulp and paper market.

Source: RISI

Historically, pulp and paper demand has not been very elastic to price (Exhibit 67). Therefore, we expect price fluctuations in the energy markets to have limited impact on global paper-products demand. In fact, past data show that the evolution of pulp and paper demand has been much more dependent on economic growth than on prices. Over the next 15 years, we foresee no major disruption to the evolution of global demand for pulp and paper.

**Exhibit 67**

**PULP AND PAPER DEMAND IS NOT HIGHLY ELASTIC TO PRICES**




Source: FAO; RISI; MGI analysis

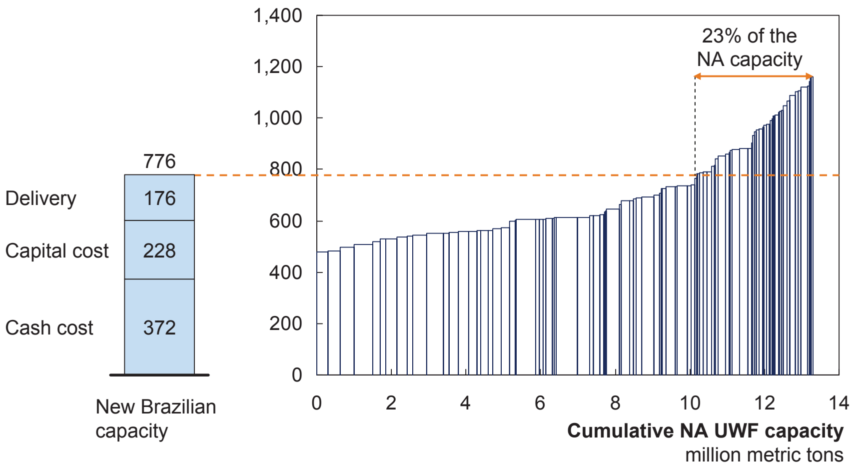
**Reinvestment economics**

From the point of view of cost—the most important elements of which are raw materials, energy, labor, and logistics—developed regions are under intense pressure. Labor and energy costs can be notably higher in the mature markets of North America and Europe, to the extent that, for comparable types of quality, local production is uncompetitive. For instance, 23 percent of uncoated wood-free paper in North America is more expensive than imported Brazilian uncoated wood-free paper, and is therefore potentially subject to direct import competition (Exhibit 68). North American pulp and paper producers have already started to feel the impact of lower-cost, foreign producers entering their local market in segments such as coated freesheet (white printing paper). Some higher-quality product grades and some other segments such as newsprint are less exposed to these relocation trends.

**Exhibit 68**

**ECONOMICS ARE FAVORABLE FOR BRAZIL TO EXPORT UNCOATED WOOD-FREE TO NORTH AMERICA**

$/FMT, delivered Chicago, IL




Source: RISI; MGI analysis

The pulp and paper industry in the United States is one of the most energy intensive in the developed world and, as many mills are in the latter stages of their economic life. In addition, because of the risk that a plant might close in the near future, energy-efficiency projects are sometimes left on the table.

We are expecting the displacement of some high-cost capacity from developed to developing regions over the coming years, although this trend is likely to be limited by the fact that developing regions have first to address growing local demand.

Strong local demand, coupled with a favorable cost position, will encourage developing regions to continue to expand their production capacity, as seen in Asia and Eastern Europe since the late 1990s. Asia leads demand growth, so most new paper mills are likely to be located there. Large investments in the pulp and paper industry are anticipated, particularly in China, which is expected to switch from pulp and paper end-product imports to raw-material imports. Fiber-rich South America has also been adding capacity to take advantage of its potential for plantation and export, with Brazil, Honduras, Chile, and Uruguay leading the way. For instance, many countries have considerably expanded eucalyptus plantations because the eucalyptus pulp price is highly competitive.

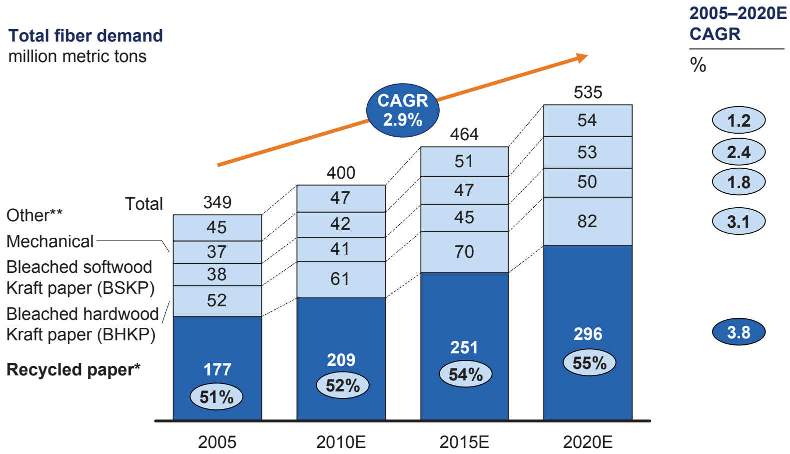
Investment in new capacity in regions with strong final demand will have a significant impact on the industry's future energy efficiency. Because modern plants are much more energy efficient, those countries building state-of the-art large-scale mills will improve their energy efficiency. Modernizing existing facilities offers the same potential, but renovating old paper mills is not always economically viable.

### Energy intensity

The evolution of energy efficiency will be the main driver of change in energy intensity in the sector. Since the 1973 oil crisis, the pulp and paper industry has been under pressure to make substantial improvements to its energy efficiency, and it has responded to a certain extent. For instance, the share of self-generated energy has increased substantially since the mid-1970s. Energy-recovery techniques have spread throughout the industry, and considerably diminished the amount of nonrenewable energy consumed. Many of the by-products of the manufacturing process can be reused as an energy resource. The most common examples of renewable energy sources include leftover wood chips, black liquor, bark, dust, and paper sludge. Increased use of energy-saving raw materials such as recovered paper has also generated cuts in energy consumption, and use of nonrenewable energy has decreased. The trend towards increased use of recovered paper is expected to be sustained (Exhibit 69).

**Exhibit 69**

**INCREASE IN RECYCLED PAPER COLLECTION AND USE WILL CONTRIBUTE TO IMPROVING ENERGY EFFICIENCY**




* Recycled paper corresponds to the amount of recycled fiber used for paper production.
** "Other includes unbleached Kraft, semichemical, and sulfite.
Source: RISI; MGI analysis

Currently, efficiency varies between regions and mills, depending on the technology employed and the age or state of modernization of the plant. Variation is sharpest among developing regions.

Both Northern Europe and Japan currently achieve high levels of energy efficiency. In the face of high energy costs, most Nordic countries have long invested in self-generating and energy-saving processes, with favorable tax rules on depreciation encouraging the building of new facilities. So Finland, for example, is one of the world's leading producers of combined heat and power. In Japan, the pulp and paper industry suffered badly from the 1970s oil crisis, and this triggered widespread upgrading to more energy-efficient capacity.

In contrast, the absence of significant investment in recent years has made North American mills relatively energy inefficient. Lower energy prices in the United States have also enabled many mills to continue using relatively inefficient technologies.

Meanwhile, in developing regions, old-fashioned small-scale mills coexist alongside new, state-of-the-art facilities. New mills in South America and Indonesia are highly energy efficient, but this is not the case with small, older plants.

Assuming future energy-efficiency improvements are in line with what has been observed in the past, we estimate that energy demand from the pulp and paper industry will grow at 1.9 percent globally to 2020.

## IV. KEY UNCERTAINTIES AROUND THE MGI BASE-CASE SCENARIO

### GDP growth

Overall economic expansion is the most important driver of energy demand growth in the industrial sector. We estimate the global elasticity of industrial energy demand growth to GDP growth at approximately 0.6. In other words, for each additional 1 percent of global economic growth, industrial energy demand increases by 0.6 percent, with the inverse also holding true (Exhibit 70).

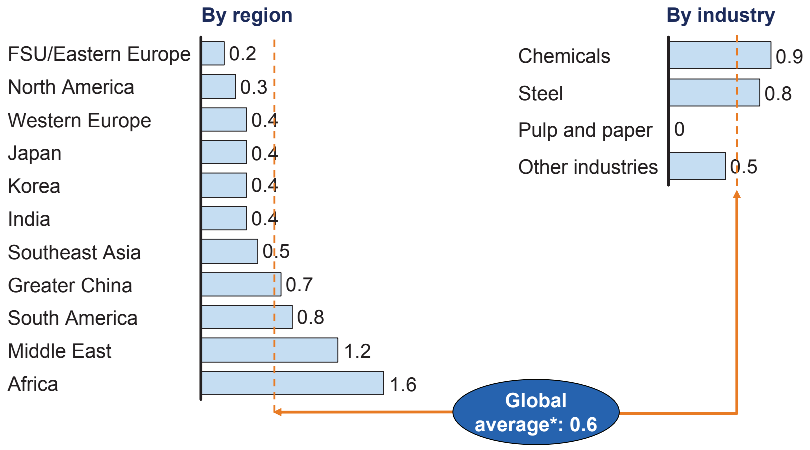
This elasticity is consistent with the fact that, as we have discussed, industrial activity broadly follows economic activity as a whole, but that service sectors account for a disproportionate share of growth in most countries, leaving the elasticity below 1.

The GDP elasticity is higher in developing regions where strong industrial growth is expected (e.g. China, Southeast Asia, and South America) and in regions that are expected to benefit from the relocation of global industries (e.g. the Middle East and China). It is lower in developed regions whose industrial sectors account for a smaller share of overall output. At industry level, elasticity to growth is higher in rapidly expanding industries, such as petrochemicals and steel, particularly in developing regions.

## Exhibit 70

### GLOBAL ELASTICITY TO GDP OF INDUSTRIAL ENERGY-DEMAND GROWTH IS ESTIMATED AT 0.6

**% change in industrial energy demand for each % change in overall GDP growth from baseline scenario**




* Based on changes between MGI GDP scenarios, where a ~0.7%% change in global GDP growth results from a 2% change in China and India, a 0.5% change in developed regions, and a 1% change in other regions.

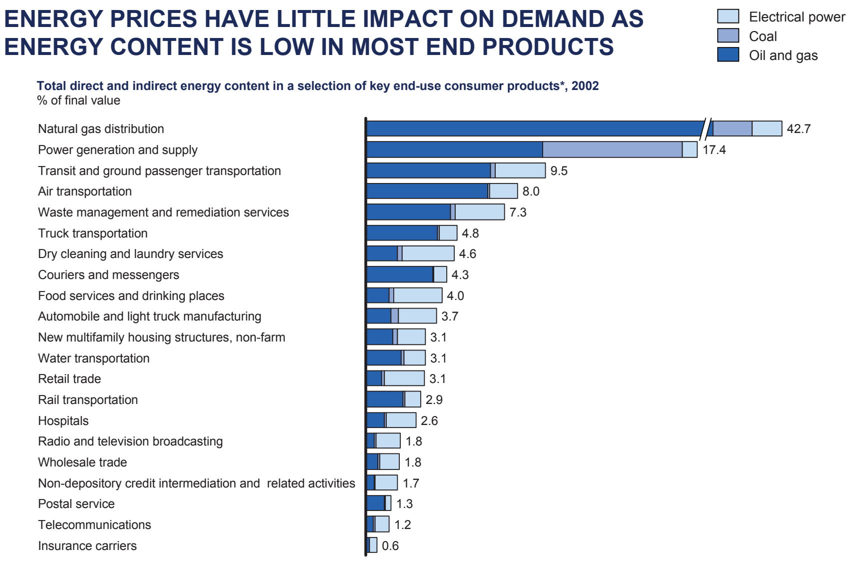
Source: MGI analysis

The measure of elasticity we use provides a direct relationship between GDP and industrial energy demand, but it should still be used with caution. Projecting industrial energy demand based solely on the elasticity figure would be to ignore the impact of energy-efficiency improvements that have a significant impact on long-term demand. The elasticity measure is also unsuitable for forecasting the effect of extreme scenarios because the GDP/energy demand relationship is nonlinear.

### Energy prices

The impact of energy prices on industrial energy demand is low. As countries become richer and GDP grows faster than industrial energy demand, economies become less energy intensive—representing a decreasing fraction of the value of end users' products. In the United States, for example, only 3.7 percent of the purchase price of a car is due to energy input during its manufacture (coal used for making the steel for the body, or petroleum products used as feedstock for the plastic parts, for instance) (Exhibit 71). Even in the case of consumers' natural-gas bills (with the highest energy content of all), 57 percent of the cost is unrelated to energy, being due instead to, for example, maintenance costs, customer service, and the capital cost of the distribution network. As a result, even a 50 percent increase in energy prices would result in only a small increase in the cost of products for final users—less than 2 percent in the case of a new car.

**Exhibit 71**




* Based on the US total requirement input-output table; includes all the direct energy inputs and the indirect energy inputs through consumption of product and services from other industries.

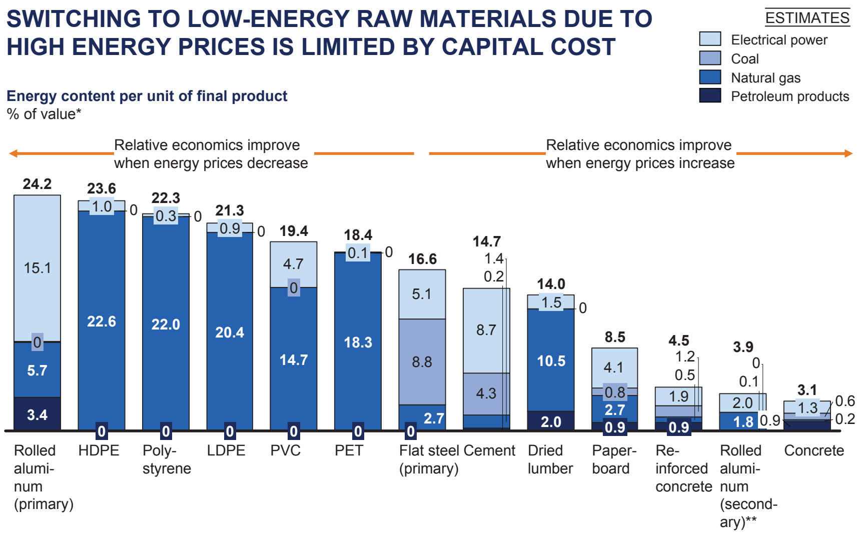
Source: BEA; MGI analysis

Of course, even if the energy content of end products is unlikely to influence consumers' buying behavior, it can still have some impact along the value chain. When energy prices rise, intermediate manufacturers may be more inclined to substitute raw materials with a high energy content for those with low energy content. However, discussion with industry experts suggests that such material substitution requires significant capital investment, and substitutes are rarely adopted solely because of short-term price changes (Exhibit 72).

### Other uncertainties

Other uncertainties, including changing regulation, may have a significant impact on how the energy demand from specific industries evolves. For instance, for the Chinese steel industry, which will be a key component of growing industrial energy demand to 2020, the national government's decision to strengthen and enforce a minimum size for steel mills would have a sizeable impact on energy demand. As energy productivity is closely related to scale in this industry, the forced closure of small mills could greatly accelerate energy-efficiency gains. In other industrial segments, the implementation and enforcement of standards could affect the demand for energy, albeit to a lesser extent.

## Exhibit 72




Note: Energy costs for a typical US operation were used; as US-based operations are at the high end of the global cost curve for many materials, we assume that the US cost structure sets the price, and therefore its relationship with energy price fluctuations.

* Based on 2000–2004 average energy prices.

** Although energy content of secondary aluminum is relatively low, its price is usually determined by the primary aluminum cost structure, which is highly sensitive to energy prices.

Source: US DOE; LBNL; USGS; BEA; *Handbook of Petrochemical Production Processes*, Meyers, 2005; MGI analysis

### V. ENERGY PRODUCTIVITY OPPORTUNITY

Our detailed case studies highlight significant opportunities for energy productivity improvement in the industrial sector, particularly in developing regions. Overall, we estimate the untapped potential to raise energy productivity to be the equivalent of 16–22 percent of global industrial end-use energy demand. This covers opportunities with an IRR of 10 percent or more.

We have based this range of figures on estimates available from several demonstration projects in the United States, calculated by the Energy Information Administration (EIA), the Lawrence Berkeley National Laboratory (LBNL), and other research groups, and from client interviews. We divide industrial sectors into three categories based on their energy use profile. For each category, we start by identifying the productivity potential in the United States as a benchmark region. We then estimate the current productivity gap between the United States and other regions. Finally, we estimate the share of this gap that can be closed economically by 2020, based on the evolution of industrial capacity going forward. In developing regions, we assume that new capacity is built at par with standards in developed regions. The China Iron and Steel Association, for example, indicates that all new steel mills currently under construction in China are at par with global energy efficiency standards.

The least significant energy productivity improvement opportunity is offered by the petrochemical industry. A large part of the energy consumed in this industry is used either as a feedstock or as an input to a chemical reaction. In the first case, a direct relationship exists between the feedstock input and the output produced. For example, the production of one ton of ammonia will always require 0.41 ton of methane (natural gas), a ratio that technically cannot change. In the second case, where energy is used as an input to chemical reactions, some efficiency gains are possible, but the chemical reaction imposes a minimum technical limit to energy input. Energy input addressable by conservation measures is therefore capped, and the economic energy productivity improvement opportunities are proportionally reduced. Across the chemicals sector overall, we estimate an economic energy productivity improvement opportunity of between 2 and 5 percent, based on the size of the "addressable" energy demand and estimates of economic improvement potential across industries.

In the steel industry, the potential is significantly larger. While energy is used in many cases as an input to a chemical reaction (e.g. coal coke acts as a reducting agent in integrated steelmaking), regional differences in energy productivity reveal significant potential for improvement. Based on academic research and experience across industries, we estimate that the most energy-efficient regions (North America, Western Europe, and Japan) have an untapped energy productivity improvement opportunity equivalent to 6–10 percent of demand. Process optimization is one important lever, where reduction in process time (e.g. in smelting, transportation between process stages, and increase in hot charging) would reduce energy losses. In developing regions, we see greater potential, since a large share of the current productivity gap with developed regions—between 10 and 20 percent—can be closed by 2020. As steel energy productivity for integrated steelmaking depends mainly on scale, developing regions can build mills that are as efficient as those in developed regions.

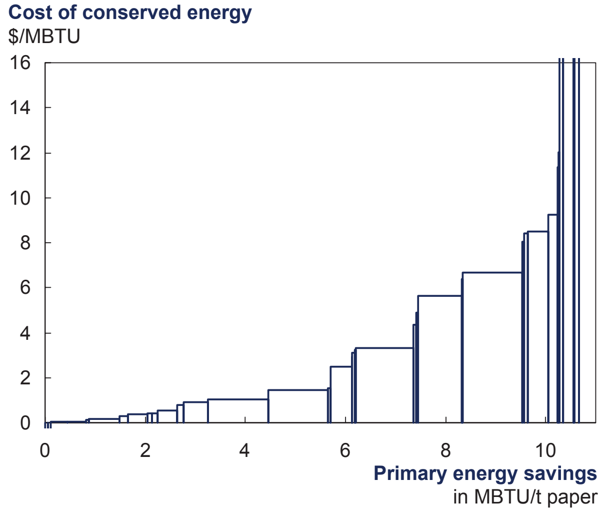
In the pulp and paper industry, analyses show that, in the US alone, untapped productivity improvement potential is equivalent to at least 20 percent of total projected 2020 demand (Exhibit 73). We assume this potential to be slightly higher in less mature economies.

A number of initiatives aimed at raising energy productivity have an internal rate of return of 10 percent or more. For example, retrofits of existing plants can save a considerable amount of energy without major capital investment. Changing the process of heat and electricity generation can also increase productivity. Because the price of electricity produced onsite is much lower than externally purchased energy, there is a strong incentive to generate electricity onsite. The heating process also offers opportunities such as energy-efficiency monitoring, effective maintenance, and a reduction of water consumption. Cutting down on power generation can be achieved by utilizing better-designed compressed-air systems, using fewer pumps, and optimizing electrical equipment.

**Exhibit 73**

**THE US PULP AND PAPER INDUSTRY HAS SUBSTANTIAL ENERGY-DEMAND REDUCTION OPPORTUNITIES**

30% DISCOUNT RATE




Source: LBNL; MGI analysis

Using cogeneration systems, which produce electrical and thermal energy simultaneously, rather than conventional boilers is a common technique in countries with limited local energy resources. Cogeneration power is now applied in about one-third of the industry worldwide, and will continue to grow. Advanced biomass-based cogeneration systems are the next-generation technologies that will be implemented.

Increased penetration of technologies enabling a switch from one type of fuel to another should also improve energy efficiency. Such technology allows for the combustion of very different kinds of fuels. For example, fluidized-bed power plants can utilize all types of biomass and fuel oil for combined power and heat production. In the United States, permits allowing such switching have so far been withheld, and this has limited the adoption of the technology.

Although the pulp and paper industry is relatively small (4.1 percent of global industrial end-use energy demand), its energy usage pattern is comparable to that of a large number of other industries. Specifically, the pulp and paper industry uses energy to generate process heat and to operate engines and machinery—uses common in other manufacturing and downstream processing industries. Parallels can therefore be drawn between the large energy productivity opportunity that has been identified in the pulp and paper industry and the likely opportunity available in other industries.

Aside from the sectors covered in our detailed studies, a good example of an industry showing room for significant energy-intensity improvement is refining. An energy audit performed by the US Department of Energy on the Martinez refinery revealed the potential for a 12 percent improvement with a two-year payback time or less. Given that US refineries are at least 20 percent more energy efficient than their developing-country counterparts, we believe that a very substantial energy productivity opportunity exists in developing regions too. Measurements of flare gas at a sample of refineries worldwide confirm this. Flare gas is fuel that could be used for energy but is instead burned and lost. We estimate that, with flare-gas recovery systems installed, the sector would achieve a global average energy productivity improvement of 30–40 percent.

Combining the energy productivity improvement opportunities across industries and regions, we estimate the potential for improvements to be between 16 and 22 percent of our forecasts by 2020. We arrive at these figures by adding to our detailed case studies an estimate of the potential in the other sectors. We obtain this estimate by allotting energy input between three industry categories: chemicals, for which we assume a 2–5 percent potential; steel, for which we assume a 14–21 percent potential globally; and all other sectors, for which we assume a 20–27 percent potential, based on our assessment of the pulp and paper and refining sectors.

**Barriers to higher energy productivity**

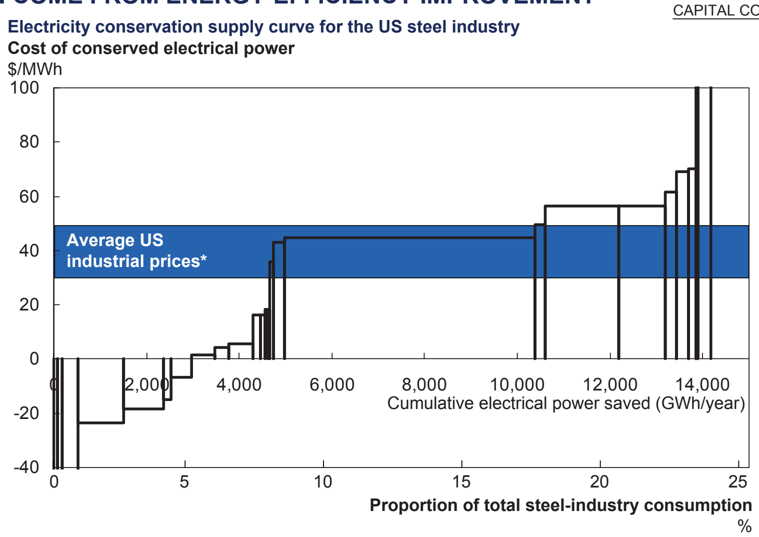
The very high payback or IRR requirements employed to evaluate energy-conservation projects in the industrial sector—typically 20 percent or more—largely explain the gap between technically-attainable energy productivity and the actual current level. In developing regions, significant government ownership of industrial enterprises and additional country-specific risks mean that payback requirements can be even higher.

New energy-conservation opportunities will be unlocked in the event of a sustained, long-term energy-price increase. Because the payback requirement for most industrial companies on energy-conservation projects is around a minimum two to five years, companies need to believe that high energy prices will last for at least that long for an investment in energy conservation to appear worthwhile. In the US steel industry, for example, an increase in US energy prices would make more conservation projects economical, including electricity conservation (Exhibit 74). The US steel industry is representative of what we observe in other industries.

**Exhibit 74**

**A SIGNIFICANT LEVEL OF ELECTRIC POWER DEMAND ELASTICITY CAN COME FROM ENERGY-EFFICIENCY IMPROVEMENT**

ASSUMES A 30% CAPITAL COST




* Estimate.
Source: LBNL; MGI analysis

We believe that a long-term increase in energy prices would advance the rate of energy-efficiency improvement in proportion to the increase in the number of energy-conservation projects available which meet most industrial companies' payback requirement. In most industries, energy prices have to increase significantly to trigger a material energy productivity improvement.

The question is, therefore, why are economic requirements so high on projects that would seem to entail a relatively low level of risk? The answer is complex. First, these projects may be more risky than they look because of the compound effect of many different factors, including project risk, energy-price volatility, and broader indirect business risks. Second, the low relative importance and fragmentation of energy costs in many industries cause some market inefficiencies.

### Economic risks

Three main economic risks are associated with energy-conservation projects:

**Project risks**—Energy-conservation projects can entail significant execution risks. Capital project cost overruns are a major problem for many industrial companies and, as a result, they tend to use higher economic hurdle rates to evaluate projects in order to account for such risk. However, when energy conservation projects are made a priority for senior managers, experience shows that project risks can be significantly reduced.

**Energy-price volatility**—In a perfect world, industrial companies could buy their energy on long-term contracts and insulate themselves from short-term energy-price volatility. However, the futures energy market is relatively thin at the medium- and long-term end, making hedging costly. As a result, most companies choose not to enter into long-term energy contracts, thereby remaining exposed to short-term energy-price fluctuations, and this is a risk they take into account when evaluating energy productivity projects. If they are evaluating a project in a high-price environment, the future value of energy savings is subject to significant risk (i.e. if energy prices go down, project benefits also fall).

**Indirect business risks**—Energy-conservation projects are almost always carried out at plant level and, even if the project promises clear benefits, management has to consider many other indirect risks that might compromise the hoped-for outcome. In mature markets, especially in the basic-materials industry, many high-cost production sites are in developed regions. What if reduced end-product prices force the company to shut down the plant? The savings from the energy-conservation project, which appeared to be safe, would be lost. Similarly, in other countries, indirect risks can include exchange-rate fluctuations or political instability.

**Additional factors**

In addition to the economic risks we have outlined, there are other factors inclining companies to increase the payback requirements that they impose on energy-conservation projects:

**Fragmentation of costs**—Although a significant component of most industrial companies' cost base, energy costs are sometimes small at the plant level, and consequently they receive little attention from management. Even when they become a priority, other barriers remain. Only a limited share of plants have energy managers or access to energy experts to design and implement energy projects. Furthermore, coordination among plants is limited. Both factors mean that in many cases the perceived risks appear to be higher than they actually are.

**Capital allocation process**—A plant's capital budget is typically separated into three broad categories: safety projects, aimed at addressing critical employee health and security issues; sustaining projects, aimed at maintaining and replacing existing equipment to ensure that long-term operations are not compromised; and payback projects, which typically consist of adding or changing pieces of equipment to save on operating costs. The first two categories understandably take priority over the third—into which energy-conservation projects usually fall. The capital available for payback projects therefore absorbs almost all the cyclicality in the capital budget. In other words, the budget is usually much higher when times are good, yet at this point top-line growth investments appear very attractive, so energy-conservation projects are rarely high on a plant manager's priority list.

**Single hurdle rate for all capital allocation**—Arguably, projects aimed at securing cost reductions—and this includes almost all energy-conservation projects—should be evaluated at a lower discount rate than output-improvement projects, which carry more inherent risk (risk of price drop, risk that the new capacity will not be fully utilized, etc.). However, a single plant-level hurdle rate is usually fixed at the corporate level.

**Government ownership**—Governments own a significant percentage of industrial plants in many countries (for instance, the Chinese government owns a large share of the steel industry), and national oil companies dominate global refinery ownership. As shown in previous MGI productivity studies, government ownership tends to reduce competitive intensity and therefore also the incentive to improve labor and capital productivity. The argument is the same with energy productivity.[3] Our estimates show that refineries owned by national oil companies (NOCs) are, in general, much less energy productive than those in the private sector.

In summary, a discount rate of about 10 percent would seem appropriate to evaluate most energy-conservation projects. However, because of the risks and market imperfections we have outlined, many sites actually use hurdle rates that are much higher—typically well in excess of 20 percent.

### Capturing the energy productivity opportunity

Tools for capturing higher energy productivity in the industrial sector are similar to other sectors, and fall into three broad categories: financial incentives (taxes and subsidies), dissemination of information, and standards and government purchasing.

3 See MGI's extensive productivity research at http://www.mckinsey.com/mgi/rp/csproductivity/

**Financial incentives:** Negative financial incentives increase the "cost of doing nothing" to corporations. These measures include increasing energy taxes to account for externalities and provide an additional incentive to improve energy productivity; and the implementation of emission trading markets (such as a cap and trade system) that increase incentives to reduce pollution and, indirectly, energy demand.

Positive financial incentives—subsidies—increase the value of energy-conservation projects. Subsidized loans earmarked for energy-efficiency projects might help in reducing discount rates, especially to the extent that they contain provisions to help mitigate some of the risks described above. These measures include increasing government-funded research on energy-efficient technologies, and providing subsidies or additional tax credits to companies implementing specific energy-conservation technologies. For example, governments might opt to finance energy-conservation projects at low rates, and perhaps allow rescheduling if plants are temporarily shut down due to market conditions.

In the large portion of industries where the value chain is global, such as in aluminum and flat steel, negative measures implemented at country level may have little long-term impact on energy conservation. They might encourage some energy productivity improvements, but with the possible perverse effect of triggering relocation of production capacity to other countries with lower energy productivity. Because of this last factor, the net impact of some of these policies could be a decrease in energy productivity and a consequent increase in global energy demand.

In light of the dynamics observed in global industries, which account for approximately one-half of the total industrial energy demand, any policy resulting in an increase in energy price should ideally be implemented in parallel with other countries, or at least only after careful analysis of the potential unintended consequences. Any policy concerned with greenhouse gas emissions falls into this category, and therefore has to be embraced throughout a significant part of the world in order to be effective.

**Information:** The second policy tool available to governments is the dissemination of information on available technologies offering a positive economic return. This increases the industrial sector's awareness of existing energy-conservation technologies. The US Department of Energy, for example, has helped perform energy assessments in order to identify savings opportunities in specific plants. Following Hurricane Katrina, they sent out a team of experts to 200 industrial plants in the United States and, even though these were already considered world-class facilities, the team identified 8 to 10 percent savings opportunities. In terms of payback, forty percent of these improvements generate energy savings that recoup the initial investment within 9 months, and seventy-five percent within 2 years.

**Standards and government purchasing:** The third set of policy tools comprises standards and government purchasing. Examples of standards include minimum energy-efficiency measures for steel plants in China (or minimum scale requirements, as scale is closely related to efficiency); a regulated closure schedule for chlorine plants using mercury-cell technology; and specific limitations on air pollution in the industrial sector. Such policies can be implemented unilaterally and are simple to communicate.

The challenge for the industrial sector is the enormous number of equipment types for which to set standards. In addition, overly-specific mandates risk dictating the precise areas for the reduction of energy demand, instead of encouraging the market to chase the lowest-cost opportunities in order to achieve the same outcome. For all of these reasons, policy makers should bear in mind that the energy efficiency of the "system" is just as important as that of its constituent components, and must seek to set standards in a such a way as to minimize distortions and maximize incentives to innovate.

Legislation imposes strict energy-intensity standards on government purchasing, and requires the implementation of energy-conservation technologies that go beyond standards in government-operated industries. Examples of such measures include the decision by several government agencies around the world to use electric cars, or the recent US government initiative encouraging employees to shut down their computers at night. In some cases, the projects may not yield direct economic benefits for the government, but they do contribute to reducing the national energy demand, and serve as an example to the rest of the society.

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